UNIVERSITY OF ALBERTA

Microclimate of Aspen Forests

BY

David Allan Chesterman

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of Master of Science

DEPARTMENT OF EARTH and ATMOSPHERIC SCIENCES

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled **Microclimate of Aspen Forests** submitted by David Allan Chesterman in partial fulfilment of the degree of Master of Science.

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Dedicated to
Jack and Ollie Chesterman
my parents

Abstract

Microclimatic parameters (photosynthetically active radiation [PAR], wind speed, air and soil temperature) were measured in three age classes (young: 20-30, mature: 50-65 and old: >100 years) of aspen (*Populus tremuloides*) forests. Microclimates at the seven sites, 2-3 replicates of each age class, were found to vary widely by site. Age classes were found to have similar microclimates. Certain stand attributes were found to correlate better to stand microclimate than to stand age.

Microclimate parameters were also measured in an aspen mixedwood forest, an aspen cutblock, and at the edge of a cut aspen forest. Microclimate was more variable in a cutblock. In the cutblock, PAR, wind, estimated potential evapotranspiration and soil temperature were greater than in the aspen forest. Mean daily air temperatures were similar for all treatments. The edge microclimate was affected by both adjacent habitats.

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1.0 INTRODUCTION

1.1 Context of mixedwood forest harvesting

Recent provincial government economic development policy plans for harvesting of the boreal mixedwood forests of northern Alberta on a massive scale. Approximately 6 x 10^6 ha of mostly aspen-dominated forests will be affected (Environmental Impact Assessment Review Board, 1990). Aspen harvesting could potentially have major ecological and climatological effects since the boreal mixedwood ecoregion covers over 40% of the province (Strong and Leggat, 1992).

In the boreal mixedwood ecoregion, indigenous people traditionally relied on the forest resources (Dempsey, 1974). In this century, the region has seen increasing recreational use and industrial developments, mainly hydrocarbon exploration and exploitation and major transportation corridors. However, agricultural use has been limited. Forestry activity has been mostly restricted to logging of conifers for merchantable wood. Hardwoods harvesting, aspen (*Populus tremuloides*) and balsam poplar (*Populus balsamifera*), has been limited to 4% of the total area logged because of their unsuitability for lumber (Seneker, 1987). Technological and economic developments now make it profitable to exploit this untapped aspen resource for pulp and strand board production. With the demise of the fur trapping way of life, forestry development offers alternatives with economic growth and employment opportunities for residents of the region.

Forest harvesting practices will change the natural age class structure and the biological diversity of the boreal forest (Hunter, 1990). Ecologically distinct "old-growth" aspen stands do exist and harvest rotation practices should ensure their presence in the future (Stelfox, 1995). Research has indicated that over-mature aspen forests have unique wildlife composition (Westworth Associated Ltd., 1984). Island biogeography principles recognize the strong relationship between the size of forest stands and their biodiversity (MacArthur and Wilson, 1967). Stelfox (1995) noted that decadent stands (>100 years), as referred to by foresters, will be eliminated due to increases in the undesirable properties of trunk rot, staining and poor fibre quality. These over-mature stands will be initially cut to encourage the regrowth of new, healthier trees of better fibre quality. Secondary forest growth will be harvested over 50-70 year cycles to maximize quantity and quality of fibre yield. Short rotation harvesting of aspen forests will prevent the development of the advanced-aged aspen stands.

This political and economic decision to cut has begun an ecological experiment at a landscape scale. Modern forestry management requires high yield and short rotation harvesting. Increasing public opposition to forestry practices has

occurred because of perceived negative impacts on soils, water quality and biological diversity (Keenan and Kimmins, 1993). Forest managers knows that their decisions will impact the boreal forest of northern Alberta (Environmental Impact Assessment Review Board, 1990). However, they do not understand what these effects will be, based on our present knowledge (Stelfox, 1995). Foresters and researchers need to recognize, define and resolve problems that will be encountered in managing the boreal forest. This study was in association with a major project on aspen forest biodiversity conducted by the Alberta Environmental Centre of the Provincial Government (Stelfox, 1995).

1.2 Aspen forest research

Existing literature on aspen forest ecology and management focuses on problems arising from the presence of aspen (Peterson and Peterson 1992). Until recently, the forest industry in Alberta has viewed aspen as a nuisance "weed tree" species with little economic value because of its competition with merchantable conifers (Peterson and Peterson, 1992). Major gaps in knowledge of aspen ecology have been recognized (Navratil and Chapman, 1991) and many critical ecological questions need to be investigated. Stelfox (1995) recommended that government and industry research the ecological impacts of forestry activity in the boreal mixedwood. He asserted that forest canopies of aspen and spruce are important to biodiversity and recommended that this interspersion of coniferous and deciduous tree species be sustained. Fire, a natural ecological process, was important in maintaining this variability at both the stand and landscape scale. Forestry management will suppress forest fires to protect the trees; therefore, one strategy would be to modify harvest practices to emulate the effects of fire on the maintenance of this biodiversity (Stelfox, 1995).

Numerous studies have measured rapid re-establishment of an aspen canopy after a disturbance (Peterson and Peterson, 1992). Aspen mainly regenerated vegetatively by suckering from the roots. Suckering can be very dense producing an aspen cover in several years. Thinning of stem densities occurs as the aspen trees grow. Aspen is considered a successional species often climaxing in a coniferous canopy, but aspen forest can be self-perpetuating if no coniferous seed source is available. Whether the climax forest is coniferous or deciduous, there are changes in both the forest structure and forest species composition as the aspen forest ages (Lee et al, 1995a; Lee et al, 1995b; Peterson and Peterson, 1992). Available information on aspen forest succession focuses on changes to plant and animal community associations rather than microclimatic differences.

The succession in the boreal forest affects many aspects of the ecosystem (Keenan and Kimmins, 1993). Microclimate is

an important component of the environment that changes as a forest ages. Trees grow and form a canopy layer reducing light, wind and temperature and thermal variability near the ground surface (Oke, 1989). Such changes in the microclimate can affect seedling survival and growth. Understorey species may become the next generation of tree canopy (Keenan and Kimmins, 1993). Also, fauna exploit forest microclimates to minimize stress, such as seeking shade on a hot sunny day. With successional development, changes in the microclimate are expected.

Shifts in the structure and composition of a forest will be accompanied by changes in the microclimate beneath the evolving aspen canopy. Microclimate under a forest canopy has been related to stand age and structure (Messier and Bellefleur, 1988; Ross et al, 1986; Whitney and Foster, 1988). Ross et al (1996) measured seasonal and successional changes in light quality and quantity in the understorey of boreal forest ecosystems, but only one of their sites was aspen-dominated, the rest were coniferous. In aspen stands, old canopies were found to transmitted greater light than younger canopies (Constabel and Lieffers, 1996). Aspen canopy openness was found to be least at maturity and greater in young and old stands (Lee et al, 1995a). Many shifts in forest structure and composition have been measured (Lee et al, 1995a; Lee at al, 1995b). How this aspen forest development influenced the understorey microclimate has not been evaluated.

Research has been restricted to instantaneous measurements of a single variable (light) under selected conditions, such as sunny days. The limitation of such research is that it ignores the fact that flora and fauna exist under both a daily and seasonal cycle. No study has yet to examine the long term microclimatic changes with the aging of an aspen forest. If the microclimate changes significantly with forest development, it could have a major effect on the flora and fauna. This will affect how the boreal mixwood forest is to be managed to sustain biodiversity.

Harvesting of the aspen dramatically altered the environment. The cut forest microclimate would be altered but so could the adjacent uncut forest environment. Because of the large scale cutting of the boreal forest of northern Alberta, local and regional climate may also be affected (Oke, 1987). Research has shown that forest regeneration and animal survival may be affected by changes of the microclimate (Hogg and Lieffers, 1991; Martell and Radvanyi, 1977).

Numerous papers have looked at the effects of logging. Keenan and Kimmins (1993) summarized the ecological effects of clearcutting of coniferous stands on microclimate. After clearcutting, shortwave radiation increased 10-20 times but net radiation decreased by 50%. Air temperature (1.5 m) diurnal range increased 2 times with a 3-5°C increase in the

daily maximum and a 1-2°C decrease in daily minimum. The ground surface maximum increased more than 20°C depending on the surface material (i.e. mineral or litter); minima were 5°C cooler. Increased soil temperature declined with depth into the soil profile. Even at 50 cm summer soil temperature increased by a much as 5°C. Precipitation reaching the soil surface increased 15-50%. There was only a small (<15%) increase in relative humidity but there was a large increase in actual evapotranspiration. Snow depth increased but snowmelt was 1-3 weeks earlier in the spring. Both wind speed and turbulence increased.

Cutting of deciduous stands also produced environmental changes, but less pronounced. McCaughey (1989) measured changes in both sensible and latent heat fluxes when a mixedwood forest in Eastern Canada was clear-cut. Preliminary results reported by Nesdoly (1994) indicate only minor differences in air and soil temperature, but wind and PAR increased between an aspen forest and a clearcut. However, he did not examine the microclimate at the forest-clearcut edge even though these borders are important bioclimatological zones and the area of greatest interaction of the forest and cutblock environments (Oke, 1987).

Forest environments directly adjacent to the clear-cuts will also be affected (Kershaw, 1991). The understorey is open beneath an aspen canopy, offering little resistance to airflow from an adjacent cutblock. The influence of an aspen cutblock microclimate on the adjacent aspen forest is also unknown.

Foresters must manage all stages of forest development. They manage more than just the trees, their decisions need to include and respond to all aspects of the environment. Microclimate indexes could potentially be used as instruments when making forestry management decisions to minimize the disturbance to the environment while maximizing healthy aspen regeneration. (DeLong, 1991). For example, by managing microclimate parameters such as runoff from harvested areas, foresters can minimize soil erosion.

1.3 Objectives

These following papers chronicle microclimate changes along a progression, from a cutblock disturbance through three stages of aspen forest succession. The first objective, addressed by Chapter 2, is to examine changes in the microclimate of three age classes of aspen forests (a young, mature and old stand) and to examine how these microclimatic differences are related to stand structure.

An aspen cutblock, forest edge and an aspen forest are different environments. Aspen harvesting operations will alter the forest landscape creating a mosaic of unique microclimates. In Chapter 3, the objective is to evaluate the

effects of an anthropogenic disturbance on microclimate in three treatments: an aspen cutblock, the cutblock-forest edge and the adjacent aspen forest.

1.4 Study Site

1.4.1 Climate

This study was located near Lac La Biche in the moist boreal mixedwood region (Figure 1.1) with seven microclimate station sites (Table 1.1). Climatic records (Atmospheric Environment, 1981a) from the town show that >60% of the 562 mm mean annual precipitation falls as rain with July the wettest month (106 mm). One thunderstorm can release more than 30 mm in a single down pour. Snowfall accounts for less than 40% of moisture but covers the ground an average of 150 days of the year. Depth of snow on the ground varies annually, the average is 56 cm with the minimum being 18 cm and the maximum 119 cm. Even with this amount of moisture the climatic moisture deficit is high in the region (Strong and Leggat, 1992).

Sunlight hours peak in summer and days are very short in winter (Strong and Leggat, 1992). Because of the latitude, the solar energy input is low, even in summer. Cloud cover from the thunderstorm storm track further reduces summer insolation. Convective cells associated with daily cloud development dominate in summer. Winter winds have little effect on the redistribution of snow cover in the forest.

The moist boreal mixedwood ecoregion has a continental climate with warm days in summer and cold ones in winter (Longley, 1970). Dry Arctic air masses dominate the region in winter and moister Pacific air mass in summer. At the meteorological station in Lac La Biche (Atmospheric Environment, 1981a), daily mean air temperature in the coldest winter month (January) was -15.2°C. The coldest recorded was -46.1°C, in January. In the hottest summer month (July), the daily mean air temperature is 14.9°C. Maximum temperature was 31.7°C in July. Mean annual temperature was at the airport was 1.1°C. The town of Lac La Biche is frost free for 101 consecutive days in the year. Soils at 5 cm remain frozen from November to March but can rise to greater than 14°C in July (Atmospheric Environment, 1981b).

1.4.2 Geology and Soils

Bedrock in the study area is Devonian and Cretaceous limestone, dolomite, evaporites and shale (Pettapiece, 1986). Unconsolidated material (morainal, lacustrine, aeolian and glaciofluvial) from the last glaciation covers the bedrock.

Mesoclimatic conditions along with the dominant vegetation cover of aspen and white spruce result in the

development on the well-drained, medium-textured glacial material of Gray Luvisols over most of the area (Wynnyk et al, 1963). Organic and Gleysolic soils develop on poorly-drained, fine-textured lacustrine material often associated with a black spruce cover. Jack pine occurs on Eutric and Dystric Brunisols that develop on well- to rapidly-drained, course-textured aeolian sediments.

1.4.3 Vegetation

Aspen dominates the tree cover with a minor component of white spruce and balsam popular (Strong and Leggat, 1992). Understorey is variable but common components were reed grass, (*Calamagrostis canadensis*), pea vine (*Lathyrus ochroleucus*), wild sarsaparilla (*Aralia nudicaulis*), bunchberry (*Cornus canadensis*), rose (*Rosa acicularis*), alder (*Alnus crispa*), beaked-hazel (*Corylus cornuta*), willows (*Salix spp.*) and saskatoon (*Amelanchier alnifolia*). Lee et. al. (1995a) measured differences in the understorey composition and Lee et. al. (1995b) found forest structure and floristic composition to be different in three age classes of aspen forest.

Table 1.1 Latitude and Longitude of Microclimate Sites

Site	Latitude	Longitude
E34	55° 47′ 23″ N	112° 48′ 15″ W
E44	55° 5′ 29″ N	112° 51′ 6″ W
M42	54° 56′ 47″ N	111° 36′ 51″ W
M46	54° 57′ 07″ N	111° 36′ 51″ W
O15	54° 50′ 28″ N	111° 33′ 1″ W
O23	54° 50′ 33″ N	111° 35′ 28″ W
O26	54° 50′ 31″ N	111° 35′ 38″ W

Figure 1.1 Location of research sites

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Stand Age Related to Microclimate of Aspen Forests[1]

2.1 Introduction

Future forest harvest practices will change the age class of the forest, thus potentially altering environments important to boreal flora and fauna. To what extent the microclimate beneath an aspen canopy changes with stand age has not been evaluated. The main objective of this study was to describe and compare microclimate differences in three age classes (young: 20-30 years, mature: 50-65 years, and old: >100 years) of *Populus tremuloides* dominated mixedwood forests of the southern boreal forest. Measured microclimate variables included wind speed, photosynthetically active radiation (PAR), air temperatures, and ground temperatures.

Boreal forest communities change in structure and species composition as the forest ages (Rowe, 1956; Harniss, 1981; Mueggler, 1985; Ellis, 1986). The botanical complexity of young stands has been described as a function of the fire intensity and the pre-disturbance community (Spurr and Barnes, 1973). Aspen stands regenerated by suckering from undamaged roots (Peterson and Peterson, 1992). Once stem dominance is established, continued suckering is inhibited by hormonal suppression (Seneker, 1977). From field observations, mature stands appear to be homogenous in their structure and composition while old stands appear to be the most heterogenous and young stands appear intermediate.

Changes in the forest canopy and understorey over time will be accompanied by changes in light, temperature, and advection beneath the developing forest canopy (Bazzaz, 1979; Ross et al., 1986; Messier and Bellefleur, 1988; Whitney and Foster, 1988). Lieffers and Stadt (1993) measured higher PAR beneath older aspen canopies. They attributed this increase to changes in the canopy structure associated with aging of the forest. This increased light level was also correlated with greater shrub cover as well as to increased height and cover of certain forbs. Rauner (1976) recognized the importance of understorey plants on the LAI (leaf area index) in a young aspen canopy. He found that total LAI did not change with stand age, but the species that comprised the LAI did. Such changes in the understorey environment should result in shifts in other microclimate parameters; this could

[1]A version of this chapter has been previously published [Chesterman and Stelfox, 1995. Relationships between microclimate and stand age and structure in aspen mixwood forests in Alberta. In Stelfox, J.B (editor) 1995. *Relationships between stand age, stand structure and biodiversity in aspen mixedwood forests in Alberta*. Jointly published by Alberta Environment Centre (AECV95-R1), Vegreville, AB, Canada and Canadian Forest Service (Project No. 0001A), Edmonton, AB pp 308].

inhibit certain species and encourage others, thus directly altering floristic composition. Hogg and Lieffers (1990) concluded that cooler soils brought about by dense *Calamagrostis canadensis* partly explained the reduced growth of conifer seedlings.

Microclimate variables are not the only ones affecting forest growth. Severson (1963) concluded that elevation and biotic factors controlled aspen understorey floristics more than did microclimatic or edaphic factors. Microtopography and canopy species influenced the spatial patterns of forest understorey plants by altering microhabitat, including the microclimatology. Soil pH, organic matter, moisture content and nutrient availability were critical ecological attributes that were affected by changes in forest attributes (Beatty, 1984). Both litter accumulation and decomposition rates were dependent on floristic composition (Sydes and Grime, 1981). Litter and plant cover greatly influenced seedbed-soil moisture and soil temperature. In the absence of fire, forest biomass and forest floor detritus increased in boreal ecosystems (Peterson et al., 1987). As organic matter accumulated it reduced summer soil temperatures and evaporation, thus promoting the build up of organic matter and thereby influencing the stand's species composition. Moss was a major producer of biomass; its increased cover in late successional stages of mixedwood forests resulted in a deepening of the organic layer (Zasada et al., 1977).

Microclimate could affect the growth and survival of a species in many ways. Van Arsdel (1965) showed that microclimate was very important in determining the characteristics of plant disease epidemics (i.e. moulds and rusts). Dispersion of spores from conk growth on aspen stems was controlled by airflow beneath the canopy.

If microclimate was found to be different beneath different age classes of aspen forests, these unique microclimates could have an important impact on both the flora and fauna. By altering the age classes of the aspen forests of northern Alberta, forest harvesting will alter the microclimate of a boreal ecosystem that covers 40% of the province.

2.2 Methods

Variation in stand characteristics was greatest between age classes (Table 2.1).

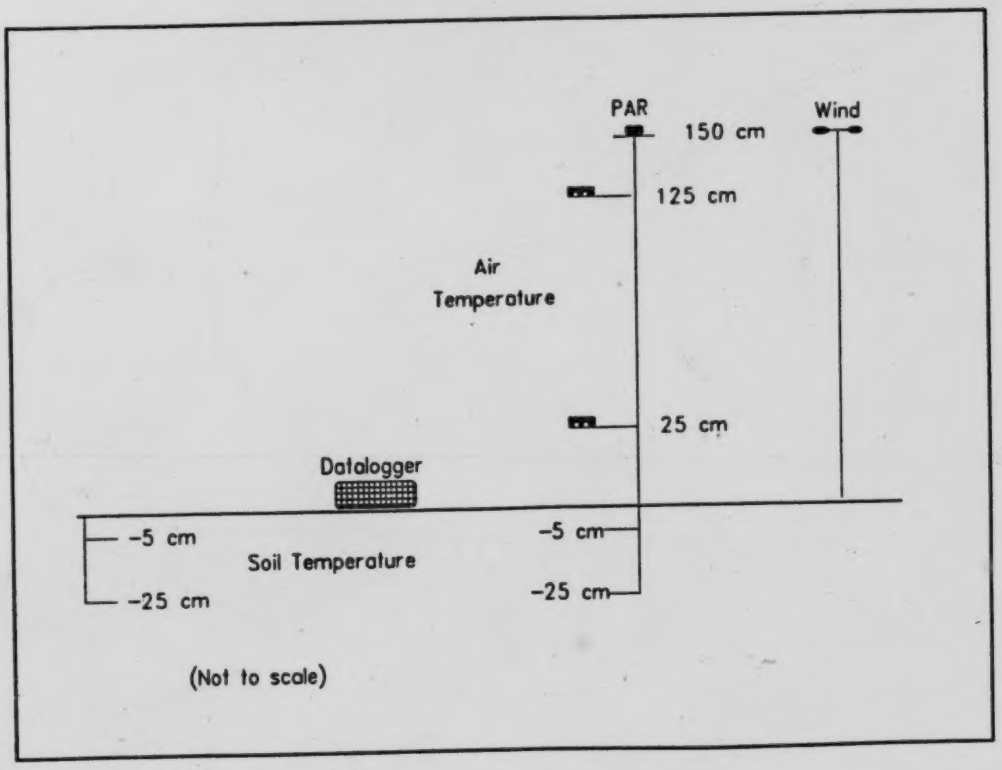
Table 2.1 Stand characteristics of research sites

Site	Age (yrs)	DBH (cm)	Stems/ha	Canopy Height (m)	Canopy Thickness (m)	Canopy Openness (%)
E34	24	8.2±1.6	2976±140	9.1±0.6	3.2±0.5	23.5
E44	26	8.1±1.1	3752±320	8.8±0.4	3.0±0.3	20.2
M42	57	13.9±1.5	2730±70	14.1±1.1	4.0±0.9	17.4
M46	57	13.2±2.9	2779±70	14.0±1.1	4.1±0.7	15.7
O15	143	38.5±10.6	788±48	22.9±3.3	5.7±1.1	18.3
O23	125	35.8±10.6	846±58	21.9±1.3	6.4±1.4	18.1
O26	125	28.0±8.8	846±58	20.7±1.4	5.6±1.1	22.3

Seven microclimate stations were located in aspen forests representing three age classes: young (n=2), mature (n=2), and old (n=3). These stands were selected based on criteria set for the larger associated study (Stelfox, 1995). Young stands were 20-30 years old (Plate 2.1), mature 50-65 years (Plate 2.2) and the old stands were more than 100 years (Plate 2.3) determined from tree rings. Microclimate stations were positioned beneath a canopy subjectively determined to be "typical" of the stand. A level topographic position was preferred, thus eliminating differences due to slope, aspect, and depressions or ridges. Microclimate stations were positioned close (50-100 m) to site centres and at least 100 m from the edge of the stand. Flora and fauna information was collected away from the microclimate stations in order to minimize trampling or disturbance of the vegetation or snowpack, but within 100 m of plot centre. Stations within the same stand were located no less than 400 m apart. At each station, the depth of the organic mat was measured and the mineral soil texture was determined using the hydrometer method (Kalra and Maynard, 1991).

Each station included one 6 channel datalogger (Lakewood UL-16), one solar sensor (LICOR LI-190SZ Quantum) which measured the photosynthetically active radiation (wavelengths of 400-700 μm, accuracy $\pm$ 5%) and was positioned 150 cm above the ground; one cup anemometer (Sims standard transducer with a threshold 0.2 m s^{-1}, accuracy $\pm$0.3 m s^{-1}) located at a 150 cm height, and; six thermistors (Lakewood LE8396 temperature probe, manufacturer's stated accuracy $\pm$0.2°C) which measured air temperatures (125 cm and 25 cm) above the ground surface and two replicates of soil

Figure 2.1 Microclimate station



temperature sensors (5 cm and 25 cm) located below the ground surface (Figure 2.1). Soil temperatures were taken at two locations (30+ m apart) to evaluate spatial heterogeneity of soil temperatures within a site. Soil sensors were located in a representative site and not beneath downed logs. Manual soil temperature readings were also taken using a Jenco 7001H model microcomputer thermometer (accuracy $\pm 0.1°C$) with copper-constantan thermocouples positioned at 50 cm depth. Air temperature thermistors were protected from direct solar radiation by a white, wooden (6 mm) radiation shield that allowed for efficient air flow. Wires were run through plastic water pipe to minimize rodent damage.

Plate 2.1 Young aspen stand with high stem density

Plate 2.2 Mature aspen stand

Plate 2.3 Old aspen stand

The datalogger read each sensor every 30 seconds and stored hourly averages for later retrieval by a laptop computer. The large number of measurements were taken to minimize sampling errors as compared to systematic errors associated with the instrumentation. Microclimate stations were visited every two weeks or monthly for maintenance and data retrieval.

Soil temperatures varied with soil surface temperature and soil thermal properties (Oke, 1989). Yearly and daily temperature cycles must also be considered when comparing temperature data. Over very short distances, Pierson and Wight (1991) measured significant soil temperature differences beneath forest vegetation. Since ground surface temperatures can be extremely variable over short horizontal distances, representative ground surface temperature measurements were very difficult to make. For this reason, soil temperatures were measured instead. These subsurface temperature measurements represent an average of surface temperatures over a larger horizontal area and integrated over time (Oke, 1989). All thermistors were recalibrated in the laboratory using a constant temperature bath prior to field installation and again when they were removed to quantify the measurement drift associated with each sensor. Wind and solar sensors were also checked for drifts in calibration. No corrections were needed because of instrument drift.

One standard copper Atmospheric Environment Service rain gauge was located in an anthropogenic forest clearing near each age class stand. The rain gauge was positioned in the clearing at least one tree height from the forest edge and 50 cm above the ground surface. Mineral oil was added to minimize evaporative losses. Rainfall gauges were checked biweekly or monthly (April - October) to monitor rainfall and determine if the three different locations were receiving different amounts of precipitation. Ideally many precipitation gauges deployed beneath the aspen canopy would have improved ability to characterize the highly variable canopy throughflow (Oke, 1989). This was not undertaken because of the problem of capturing the same precipitation event.

Snowpack depth measurements were made at approximately 2 m intervals along a transect at each microclimate site. Snow surveys were made when the microclimate stations were serviced. Warm weather conditions did not permit snow density measurements.

A clinometer and tape were used to measurement canopy height, canopy thickness, and stem diameter at breast height. These tree measurements were taken near the location of the PAR sensor and compared with sky cover on photographs taken with a 180° fish-eye lens at each sensor. This data was collected for each age class to provide assistance in the interpretation of the results from radiation measurements.

Animal damage, in the summers of 1992-93, mostly consisted of mammals (bear and deer) removing the solar radiation shields from the air thermistors. A little data was lost as a result of small mammals chewing through exposed cables. Another minor problem was that bears punctured the datalogger shelters. Several anemometer cups were damaged; data were lost when all or part of a cup was removed. The

effect on the anemometer accuracy when an anemometer cup was partially damaged was not determined. These data were excluded from the analysis. On several occasions a precipitation gauge was tipped over by bears, resulting in loss of data. Information was also lost when rain gauges overflowed. These problems were minimized by reducing the time between visits to the sites.

2.3 Data Analysis

First, age class data were pooled to compare age classes and then site-to-site comparisons were made to determine if age class differences or similarities were the product of an individual site. Comparisons were done on hourly, monthly and seasonal intervals to examine short to long term variability. Monthly and daily temperature averages and standard deviations were calculated and used to compare (t-test) age classes and sites. Daily temperature ranges were examined (one-way ANOVA and Tukey-HSD test) to determine if stands of certain age classes were more diurnally variable. The Kolmogorov-Smirnov goodness of fit test was used to verify normality of data before running parametric analysis. Total rainfall and snowpack depth were used to compared stands to determine if precipitation variation could explain radiation, wind, or temperature differences among stands. Rainfall and snow depth data were compared with t-tests.

Microclimatic variables were compared with environmental variables to test whether there were differences in microclimate within and between different aged stands. Attributes were chosen due to their expected influence on the forest microclimate (Oke, 1989). Thirteen environmental variables were selected from the data base of the associated biodiversity project.

2.4 Results

2.4.1 Soils

Soils attributes varied over the undulating topography. Orthic Gray Luvisol and Eutric Brunisols dominated the upland aspen portion of the catena (Wynnyk et al., 1963). Soil texture was mostly clay-silt except one young site that was much more sandy (Table 2.2).

Organic matter thickness measured directly above the soil temperature sensors indicated that old stands had the thickest organic matter, whereas young stands had intermediate depths and mature stands the thinnest layer, (Table 2.2). This pattern was not observed in the data collected from the 72 sites of the biodiversity project, which did indicate an increase in the amount of organic matter with the age of aspen stands.

TABLE 2.2 Soils texture and organic matter depth at the microclimate sites

Site #	Sand	Silt	Clay	Mineral Soil Texture	Organic Matter (cm)
Y-3-4	6.4	45.9	47.7	silty loam	8.0
Y-4-4	47.4	22.8	29.9	sandy clay loam	6.0
M-4-2	17.1	47.0	35.9	silty clay loam	4.0
M-4-6	15.5	40.1	44.4	clay	7.5
O-1-5	12.4	50.6	37.0	silty clay loam	8.0
O-2-3	11.2	43.3	45.5	silty clay	15.0
O-2-6	21.6	50.9	27.4	clay loam	6.0

Upper 25 cm of the mineral soil

2.4.2 Precipitation

Rainfall differences could be significant for a single sampling period, if there was no precipitation at one stand. Because of lost data due to bear damage or overflowing of rain gauges, rainfall could only be compared over those intervals with data from all sampling sites. One-way ANOVA analysis indicated that there were no statistical differences (F=0.05) among stands (Table 2.3).

TABLE 2.3 Precipitation measurements (mm), 1992-93

# samples	Young	Mature	Old	F Ratio
7	212.7	203.2	---	0.0001
8	188.8	---	183.3	0.1030
9	---	193.4	206.6	0.1324
6	100.2	105.1	112.3	___

Data missing for some sampling periods.

TABLE 2.4 Snow depths (cm) by site on January 19-20, 1993

	Y-3-4	Y-4-4	M-4-2	M-4-6	O-1-5	O-2-3	O-2-6
Mean Std	23.9 ±2.0	22.1 ±0.9	27.0 ±2.1	28.4 ±1.5	34.1 ±2.1	28.4 ±2.1	29.5 ±2.2
Min	21.6	20.3	21.6	24.1	30.5	22.9	25.4
Max	27.9	24.1	30.5	30.4	38.1	31.7	35.6
Mean Std	23.0 ±1.8		27.7 ±1.9		30.7 ±3.2		

Sample (n=20) per site
Std = standard deviation

Table 2.5 Daily average aspen forest light, wind and temperature

	Month	Young	Mature	Old	F-ratio
Temperature 125 cm	Dec	-19.5 ±9.6	-20.2 ±9.8	-19.9 ±10.0	0.710
Temperature 125 cm	July	13.2 ±2.6	13.5 ±2.7	13.0 ±2.2	0.473
Temperature 25 cm	Dec	-20.0 ±9.3	-20.6 ±9.6	-20.6 ±9.9	0.109
Temperature 25 cm	July	13.7 ±2.3	14.0 ±2.5	13.7 ±2.3	0.487
Temperature -5 cm	Jan	-6.4 ±1.8	-3.6 ±1.3	-3.4 ±0.8	114.0*
Temperature -5 cm	Aug	12.5 ±2.0	12.8 ±2.1	12.4 ±1.9	1.445
Temperature -25 cm	Jan	-5.3 ±1.2	-1.4 ±1.2	-2.3 ±0.6	330.5*
Temperature -25 cm	Aug	11.7 ±1.4	12.2 ±1.3	11.6 ±1.6	8.689
Photosynthetically Active Radiation	May - Aug	303.6	271.9	307.0	4.265*
Wind	May - Oct	0.70	1.09	0.94	19.52*

(pooled data 1992-93)
Temperature (°C)
PAR (μmoles m^{-2} s^{-1})
* significantly different (F=0..05)
F= 0.05
Wind (m s^{-1})

Significant spatial variability of snowpack occurred between stands (Table 2.4). Geographically closer mature and old stands had average snow depths that were statistically different ($t=3.60$, $P=0.05$). The more distal young stands were different from the old stands ($t=9.38$) and the mature stands ($t=8.03$). Snowpack differences were due to snowfall differences and not stand characteristics, based on field observations.

Standard deviation of snow depth was much greater in the old stands compared with the mature stand. Examining snow data for each site, it was evident that spatially closer old sites (O-2-3 and O-2-6) were significantly different from the more distant (O-1-5) site. Standard deviation in snow depth within an age class was less than between age classes (Table 2.4). Based on field observations, it appeared that variation in snow depths between mature and old sites was attributable more to differences in the amount of snowfall at sites rather than to the effects of the age class.

2.4.3 Air Temperature

Monthly air temperatures at 125 cm were not significantly different among age classes (Figure 2.2). Daily average air temperature even during the hottest and coldest months were not significantly different (Table 2.5). Year-to-year monthly temperature averages at 125 cm varied more than 2°C. Hourly average temperatures were not significantly different ($P=0.05$) between age classes (Table 2.6). Site-to-site comparison of hourly differences were not significantly different between or within an age class.

Monthly air temperatures at 25 cm were not significantly different between age classes (Figure 2.3) except for one month. In January 1993, the young stands were colder than the older stands. Daily average air temperatures during the hottest and coldest months were not significantly different (Table 2.5). The difference in the average monthly air temperature was greater on a year-to-year basis than among sites or stands in the same year. In 1992, the average monthly temperature in July was more than 2°C warmer relative to 1993 and the standard deviation was 0.8-1.3°C greater. Hourly average air temperature differences between sites at 25 cm were not significantly different between age classes. Site-to-site comparisons produced no significant differences both between and within an age class. Site differences were not consistent from month-to-month or year-to-year. Air temperature variations at a 25 cm height were less than those at a height of 125 cm.

TABLE 2.6 Mean hourly temperatures differences and standard deviation between sites at 125 cm above the ground surface, July 1993

Site	O-2-3	O-2-6	M-4-2	M-4-6	E-3-4	E-4-4
O-1-5	0.34 ±0.89	0.08 ±1.04	-0.19 ±1.39	-0.38 ±1.06	-0.06 ±2.11	-0.45 ±1.64
O-2-3		-0.23 ±0.40	-0.51 ±1.09	-0.70 ±1.08	-0.33 ±1.72	-0.81 ±1.47
O-2-6			-0.29 ±1.06	-0.47 ±1.15	-0.11 ±1.66	-0.55 ±1.47
M-4-2				-0.19 ±0.63	0.18 ±1.67	-0.32 ±1.60
M-4-6					0.37 ±1.87	-0.12 ±1.56
E-3-4						-0.41 ±1.04

Figure 2.2

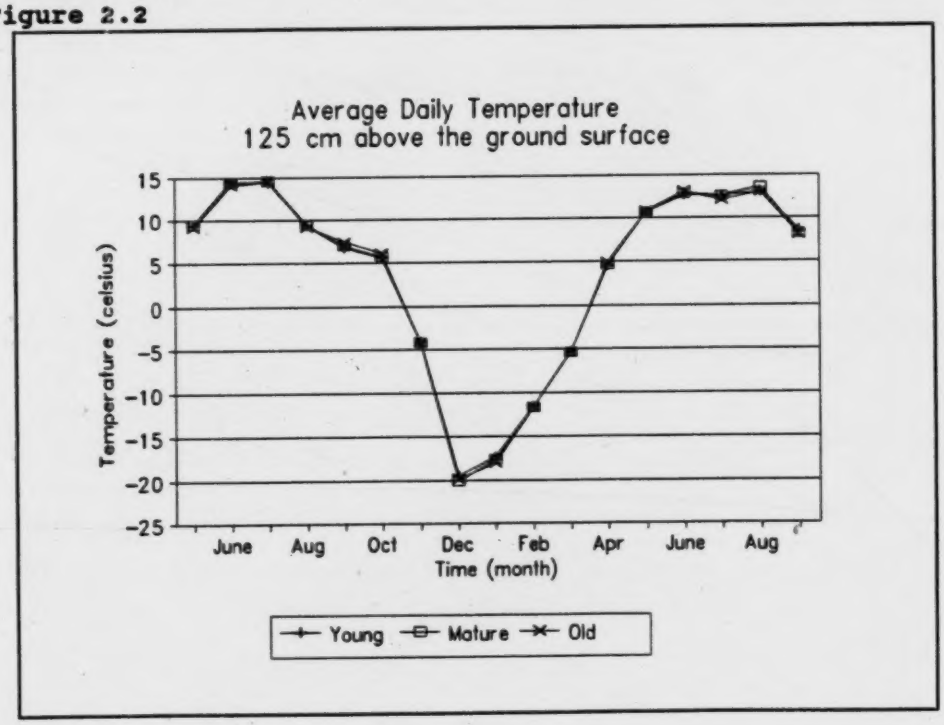


Figure 2.3

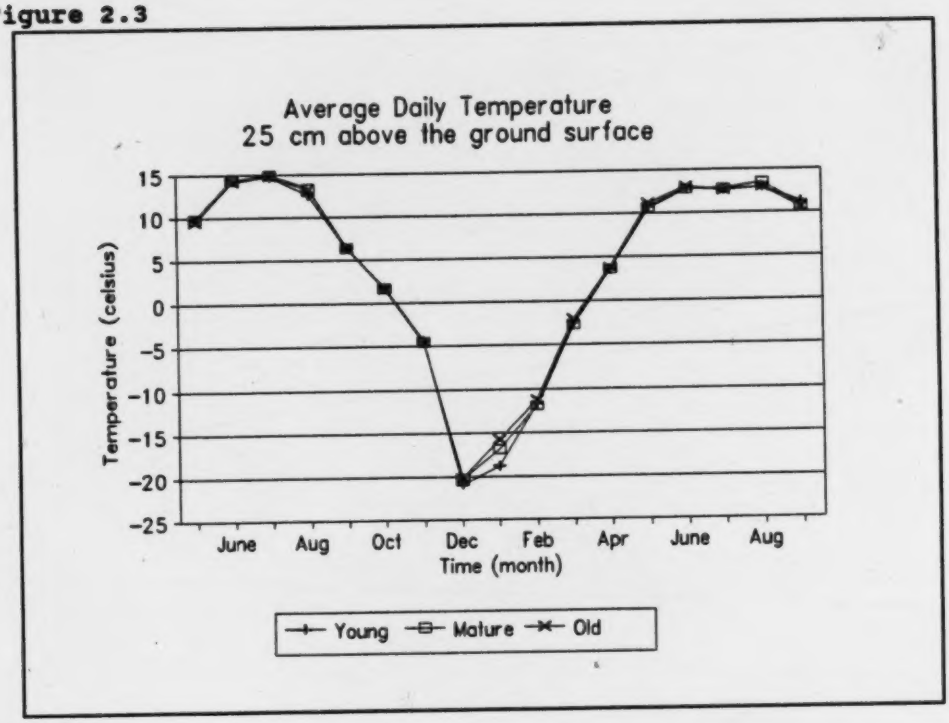

Average Daily Temperature
25 cm above the ground surface
Temperature (celsius)
15
10
5
0
-5
-10
-15
-20
-25
June
Aug
Oct
Dec
Feb
Apr
June
Aug
Time (month)
Young
Mature
Old

Figure 2.4

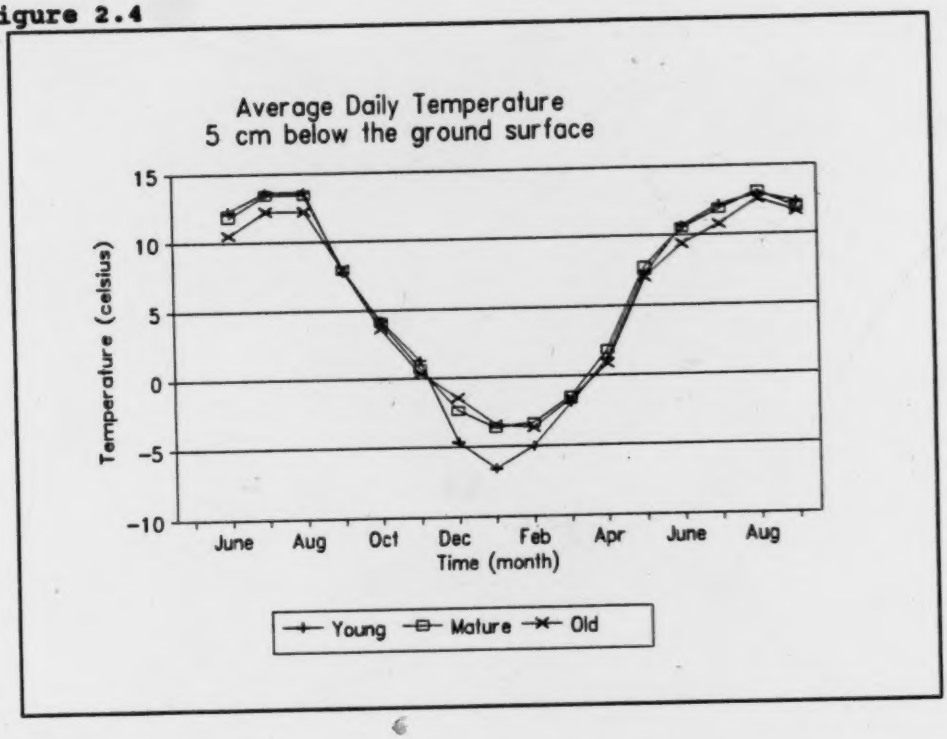

Average Daily Temperature
5 cm below the ground surface
Temperature (celsius)
15
10
5
0
-5
-10
June
Aug
Oct
Dec
Feb
Apr
June
Aug
Time (month)
Young
Mature
Old

Figure 2.5

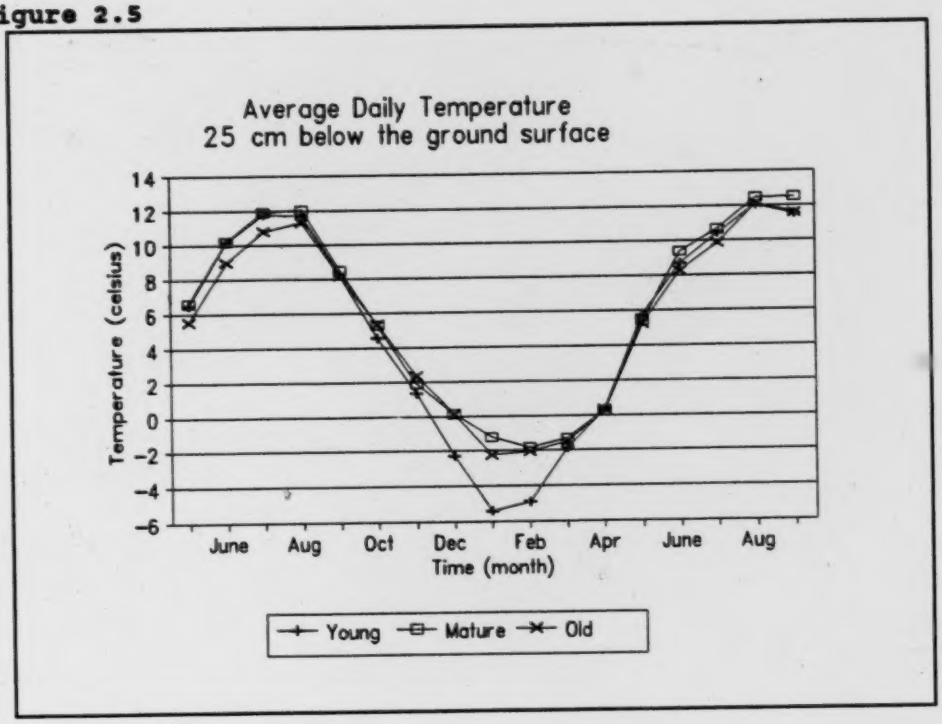

Average Daily Temperature
25 cm below the ground surface
Temperature (celsius)
14
12
10
8
6
4
2
0
−2
−4
−6
June
Aug
Oct
Dec
Feb
Apr
June
Aug
Time (month)
Young
Mature
Old

TABLE 2.7 Differences in daily temperature range at 125 cm among study sites, 1992-93

		a	b	c	d	e	f	g
	F ratio	Y-3-4	Y-4-4	M-4-2	M-4-6	O-1-5	O-2-3	O-2-6
May	1.895	12.1	12.6	15.6	14.3	13.1	11.5	12.1
June	2.082	12.2	12.7	11.4 e	11.3 e	15.0 cd	13.6	12.8
July	4.519	13.6	13.3	12.0 e	12.0 e	16.4 cd	14.8	14.1
Aug	2.294	13.7	13.8	12.2	11.3 e	14.9 d	14.7	13.8
Sept	1.230	11.1	10.1	8.2	11.1	9.3	9.5	8.7
Oct	2.222	11.4 e	10.0	9.2	8.2	7.4 a	8.8	9.0
Nov	2.587	7.7 de	5.9	5.6	4.4 a	4.6 a	5.6	5.7
Dec	12.62	12.4 bcdefg	9.3 ae	9.9 ade	7.7 a	6.8 abcfg	9.0 ae	9.0 ae
Jan	13.16	16.14 bcdefg	12.14 ade	11.51 a	9.35 ab	9.00 ab	10.8 a	11.4 a
Feb	2.982	12.6 eg	10.2	10.4	9.2	8.5 a	9.7	7.1 a
Mar	0.452	8.8	9.8	8.4	9.2	9.2	9.7	8.8
Apr	0.473	10.2	9.9	8.5	9.1	9.3	9.5	8.9
May	1.272	15.5	14.2	13.2	14.2	14.6	13.6	12.2
June	2.084	13.8	12.4	10.2	10.4	11.2	11.6	10.3
July	4.608	12.1 e	12.3	10.4 a	10.4 a	15.0 acd	13.3	12.5
Aug	6.251	14.1 def	13.2 de	11.7	10.0 ab	8.9 ab	10.7 a	11.9
Sept	4.547	14.8 def	12.9	12.3	7.2 a	9.6 a	11.3 a	11.9

Letter indicates sites that were significantly different (F=0.05)

2.4.4 Soil Temperature

Over the study period, monthly average temperatures 5 cm below the ground surface were significantly different among age classes only during the summer of 1992 and during the winter of 1992-1993 (Figure 2.4). Mature and young sites were more similar than were old and mature sites while the greatest difference was observed between old and young sites. Hourly comparisons of soil temperatures showed that age classes were not significantly different, but site-to-site comparisons among sites in different age classes were. Sites that were significantly different one month were not necessarily different the next month. Site and time differences appeared to be more important than age class in determining the soil temperature.

Monthly average temperatures at 25 cm below the ground surface were significantly different among age classes (Figure 2.5) in summer and winter. Limits of the thermistor accuracy ($\pm$0.2°C) could account for part of the 0.4°C difference between the young and the mature stands for part of the time. All sites were different, the two young sites had the greatest temperature difference. Mature and young sites were more similar than old versus mature sites with old versus young sites having the greatest difference. Hourly comparison of -25 cm soil temperatures, site-to-site, were significantly different within and between age classes. Age classes were not significantly different, based on hourly comparisons.

Average soil temperatures at 50 cm were significantly different (P=0.05) between old versus mature (t=-6.442) and mature versus young (t=4.865) age classes, but there was no significant difference between old and young (t=-0.649) age classes. At a 50 cm depth, relative differences between age classes were less than at -5 cm or -25 cm depth. This trend was expected as the thermal gradient in the soil should decrease with depth (Sellers, 1965).

Average hourly temperature in the warmest month had a greater diurnal temperature fluctuation in young sites than was the case for older stands (Figure 2.6), but in the coldest month, the old stands had the greatest diurnal fluctuation (Figure 2.7). This temperature trend also occurred at 25 cm above the ground surface (Figures 2.8 and 2.9). Site characteristics had a strong influence on the degree of diurnal fluctuation. For 6 of the 17 months (Table 2.7), there were no significant differences in daily temperature range at 125 cm height. One young site (Y-3-4) fluctuated more than the other sites. The geographically closer old sites (O-2-3 and O-2-6) were the most similar. The greatest diurnal air temperature ranges occurred in the full foliage months (summer) and the winter months when snow was on the ground.

Figure 2.6

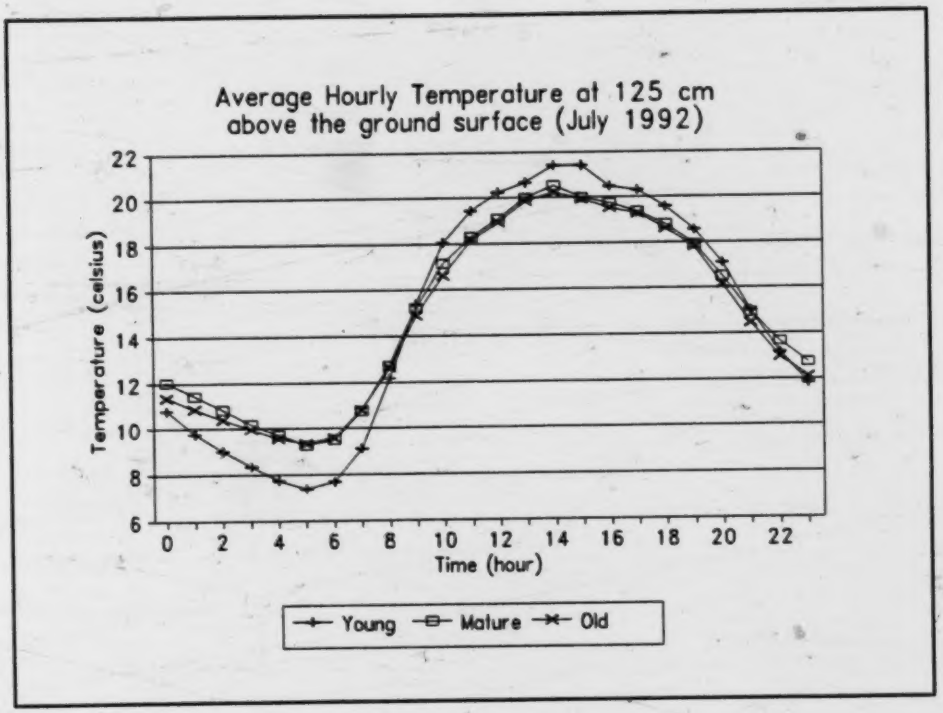

Average Hourly Temperature at 125 cm above the ground surface (July 1992)
Temperature (celsius)
22
20
18
16
14
12
10
8
6
0
2
4
6
8
10
12
14
16
18
20
22
Time (hour)
Young
Mature
Old

Figure 2.7

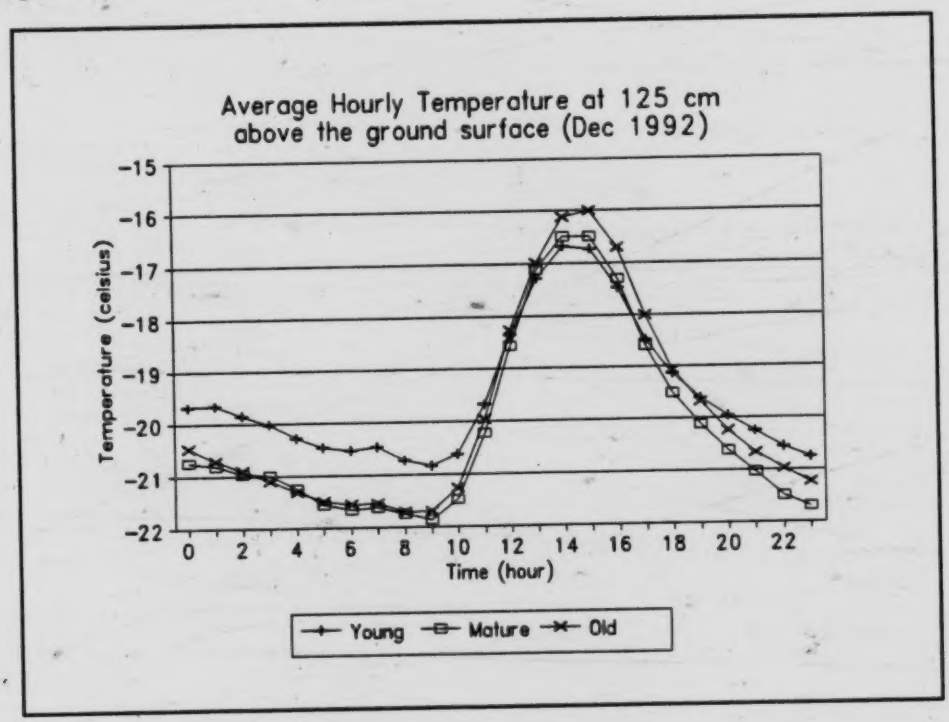

Average Hourly Temperature at 125 cm above the ground surface (Dec 1992)
Temperature (celsius)
-15
-16
-17
-18
-19
-20
-21
-22
0 2 4 6 8 10 12 14 16 18 20 22
Time (hour)
Young
Mature
Old

Figure 2.8

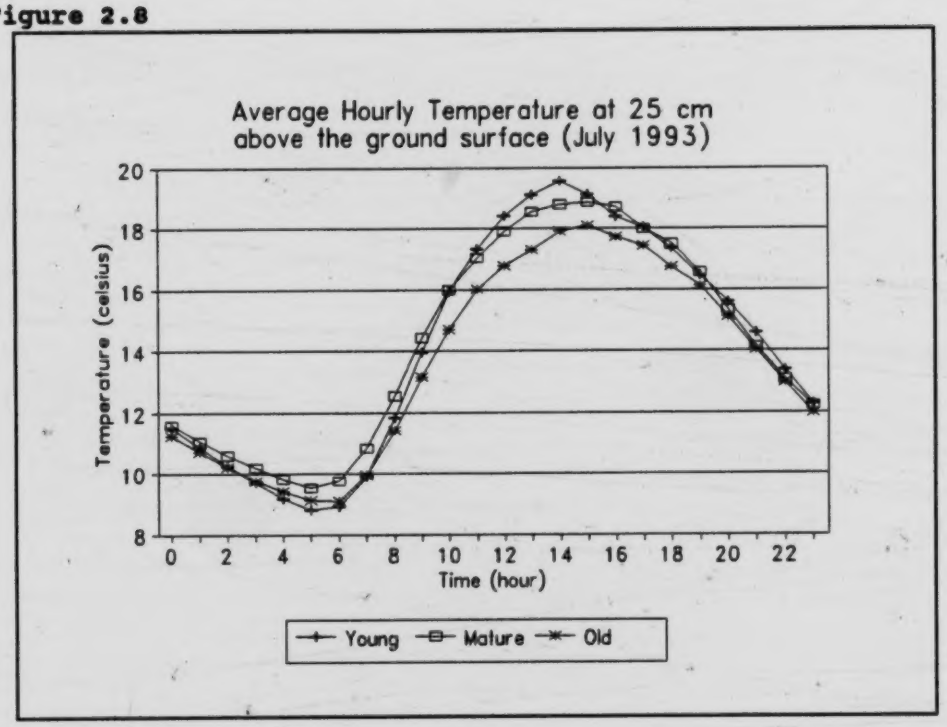

Average Hourly Temperature at 25 cm above the ground surface (July 1993)
Temperature (celsius)
20
18
16
14
12
10
8
0
2
4
6
8
10
12
14
16
18
20
22
Time (hour)
Young
Mature
Old

Figure 2.9

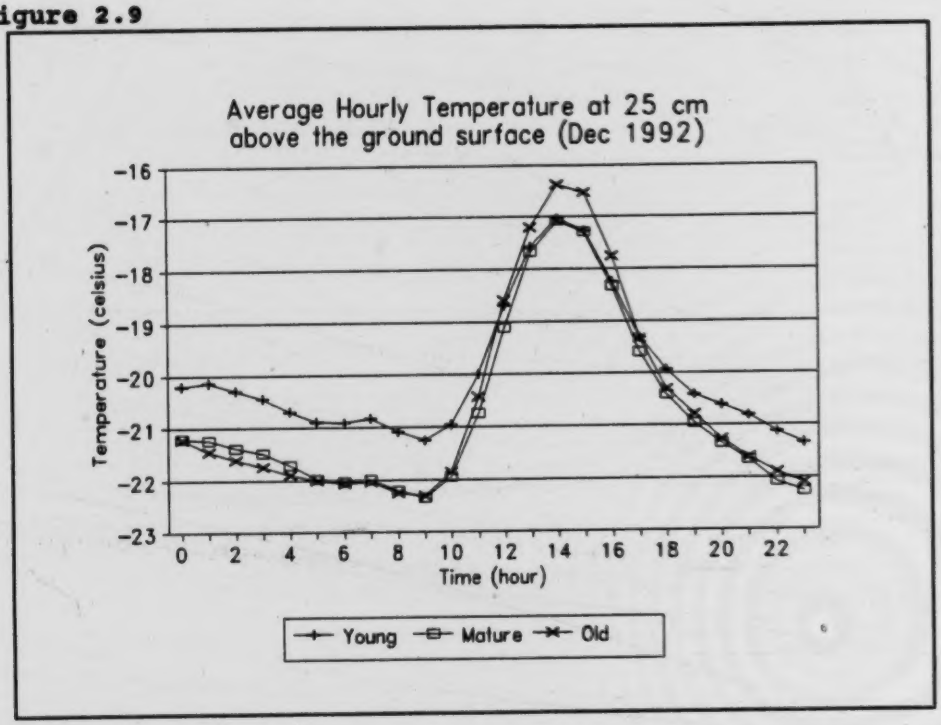

Average Hourly Temperature at 25 cm above the ground surface (Dec 1992)
Temperature (celsius)
-16
-17
-18
-19
-20
-21
-22
-23
0 2 4 6 8 10 12 14 16 18 20 22
Time (hour)
Young
Mature
Old

Figure 2.10

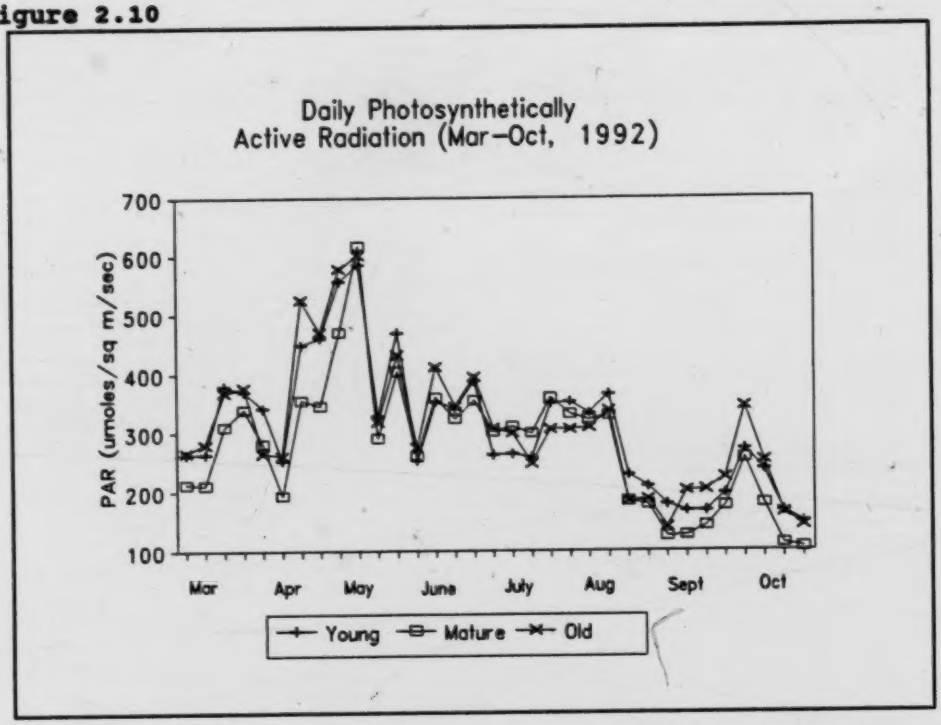
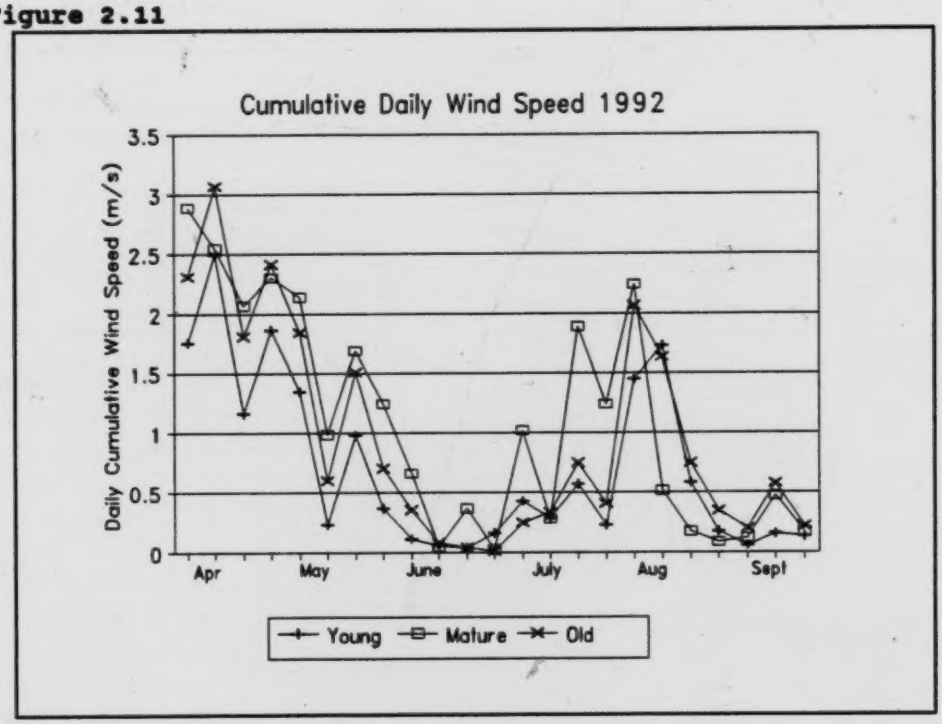

Daily Photosynthetically
Active Radiation (Mar–Oct, 1992)
PAR (umoles/sq m/sec)
700
600
500
400
300
200
100
Mar
Apr
May
June
July
Aug
Sept
Oct
Young
Mature
Old

Figure 2.11


Cumulative Daily Wind Speed 1992
Daily Cumulative Wind Speed (m/s)
3.5
3
2.5
2
1.5
1
0.5
0
Apr
May
June
July
Aug
Sept
Young
Mature
Old

2.4.5 Photosynthetically Active Radiation

In May, PAR values were greater than those of June because of the lack of foliage at the beginning of spring (Figure 2.10). Daily differences in PAR among age classes appeared small, but cumulative PAR values over the summer showed that mature stands had the lowest daily PAR value and the oldest stands had the greatest light levels (Table 2.5). Site comparison found greater light differences between sites than among age classes. Cloud cover reduced the differences in PAR values.

2.4.5 Wind

Winds were only recorded 30% of the time. Winds were found to be more variable within an age class than among age classes. Wind speed peaked in early spring before the plants were in full foliage (Figure 2.11). The fastest wind speeds were due to regional thunderstorms that created a sharp rise in the wind speed with the result that site and stand differences were minimized.

2.4.6 Correlation to forest attributes

Environmental variables (n=13) were tested for correlations with microclimate variables (N=5). The environmental variables included stem density of live trees (SDLT), stem density of softwoods (SDST), stem density of hardwoods (SDHT), diameter at breast height (DBH), tree height (HT), volume of fine downed woody material (FDWM), volume of coarse downed woody material (CDWM), number of shrub stems/100 m transect (# Stems), number of berry shrub stems/100 m transect (# BS), percent grass cover (% Grass), percent herb cover (% Herbs), percent shrub cover (% Shrubs), and depth of organic matter (OM) were. Only the environmental variables that were thought to influence microclimate variables were chosen for correlation. The microclimate variables were PAR, air temperature (125 cm and 25 cm) and soil temperature (5 cm and 25 cm). Wind speed was excluded because of low velocities. Environmental variables were tested only against summer microclimate data because of the strong seasonality of the biological attributes.

Table 2.8 Correlation (R) of air temperature (125 cm) to environmental attributes

	June 92	July 92	Aug 92	July 93	Aug 93	Sept 93
SDLT	0.6149	-0.2577	-0.634	0.6536	-0.0986	0.7563
SDST	-0.0233	0.2553	0.7113	0.0429	0.5775	-0.4494
SDHT	-0.2633	0.4734	0.3191	-0.3796	0.0228	-0.1564
DBH	-0.6	0.26	0.401	-0.6673	-0.0784	-0.5728
HT	-0.6254	0.2682	0.5076	-0.6729	0.0028	-0.6745
FDWM	0.641	0.0357	-0.5344	0.7305	0.1059	0.7182
CDWM	-0.3991	0.2178	0.2192	-0.3382	0.0048	-0.3615
# Stems	-0.5516	-0.4541	-0.3321	-0.7015	-0.7406	-0.2577
# BS	0.1682	-0.1132	0.0098	-0.0057	-0.1262	0.2629
% Grass	0.8452	0.1492	-0.1899	0.8428	0.3348	0.8081
% Herbs	0.6913	0.8742	0.7154	0.6258	0.9407	0.3215
% Shrubs	-0.5911	-0.1007	-0.0544	-0.7092	-0.4349	-0.4957
OM	-0.4432	-0.6220	-0.7379	-0.5095	-0.8868	-0.0562

The herb and grass cover were positively correlated with air temperature while shrub and DOM were negatively related (Table 2.8). Both OM and % herbs had higher correlation values, but correlation to certain variables changed widely from month to month and from year to year.

Table 2.9 Correlation (R) of air temperature (25 cm) to environmental attributes

	June 92	July 92	July 93	Aug 93	Sept 93
SDLT	0.6177	-0.2856	0.3925	-0.2274	0.7450
SDST	-0.1022	0.4011	-0.0463	0.6568	-0.3541
SDHT	-0.2244	0.2726	-0.0631	-0.1387	-0.3271
DBH	-0.5593	0.1809	-0.3255	-0.2256	-0.6477
HT	-0.5965	0.2249	-0.3505	-0.1278	-0.7240
FDWM	0.7753	-0.2801	0.5701	0.0629	0.5110
CDWM	-0.3213	-0.1773	-0.0628	-0.0013	-0.5849
# Stems	-0.5058	-0.3133	-0.6032	-0.7319	-0.0818
# BS	-0.0576	0.3805	-0.1233	-0.0671	0.5277
% Grass	0.8049	0.0518	0.5241	0.4793	0.7692
% Herbs	0.6805	0.7306	0.4723	0.9305	0.2104
% Shrubs	-0.3374	-0.2803	-0.5653	-0.5273	-0.4730
OM	-0.2553	-0.7886	-0.4665	-0.8338	-0.0064

The % herbs, % shrubs, number of shrub stems, coarse woody material, and organic matter depth maintained positive or negative correlation (arithmetical sign) with air temperature at a 25 cm height. For at least one month these variables, were highly correlated but not consistently over the summer.

Table 2.10 Correlation (R) of soil temperature (-5 cm) to environmental attributes

	June 92	July 92	Aug 93	Sept 93
SDLT	0.8778	0.8219	0.3959	0.846
SDST	-0.008	0.0488	0.2194	-0.4028
SDHT	-0.7784	-0.6716	-0.172	-0.3213
DBH	-0.9588	-0.8915	-0.4532	-0.6909
HT	-0.9530	-0.8816	-0.4365	-0.7748
FDWM	0.7321	0.8217	0.5745	0.8686
CDWM	-0.4134	-0.2295	0.0418	-0.3357
# Stems	-0.5033	-0.7004	-0.8141	-0.3806
# BS	0.0294	-0.1823	-0.2251	0.0559
% Grass	0.9469	0.9655	0.7654	0.8495
% Herbs	0.2162	0.3746	0.7896	0.2657
% Shrubs	-0.7309	-0.7854	-0.6797	-0.5377
OM	-0.1299	-0.2709	-0.6117	-0.0406

Habitat variables displayed stronger correlations to soil temperatures than air temperatures. Of all the microclimatological parameters measured, temperatures at -5 cm had consistently high correlations with environmental variables. FDWM , % shrub and % grass cover had the highest correlation with the -5 cm soil temperature (Table 2.10). Tree attributes of SDLT, SDHT, DBH, and the number of shrub stems/100 m also had high positive or negative correlation values over most of the summer. Month-to-month reversals of correlations occurred for several of the forest attributes, because of the weak correlation. Foliage developed in spring or leafall in autumn could cause this change.

Table 2.11 Correlation (R) of soil temperature (-25 cm) to environmental attributes

	June 92	July 92	July 93	Aug 93
SDLT	0.6291	0.5422	0.4346	-0.0739
SDST	0.1356	0.1241	0.3153	0.3908
SDHT	-0.4598	-0.3135	-0.3827	0.0731
DBH	-0.7155	-0.5941	-0.5911	-0.0526
HT	-0.7031	-0.5887	-0.5501	-0.0085
FDWM	0.5698	-0.5977	0.3526	-0.1706
CDWM	-0.1311	0.0265	-0.0513	-0.0566
# Stems	-0.6942	-0.7509	-0.6978	-0.4806
# BS	0.0	-0.1503	0.0364	0.3443
% Grass	0.9094	0.8511	0.8204	0.2776
% Herbs	0.5101	0.5764	0.6139	0.5852
% Shrubs	-0.8791	-0.8169	-0.8575	-0.6918
OM	-0.4553	-0.4805	-0.5719	-0.8164

Soil temperature at 25 cm was highly correlated to percent cover of grasses, herbs and shrubs, as well as, depth of organic matter, and number of shrub stems/100 m. FDWM that correlated with shallower soil temperature (-5 cm) did not correlated to soil temperature at a -25 cm depth (Table 2.11). Organic matter was more strongly correlated to deeper soil temperatures than shallow soil temperatures. A few forest variables had high significant correlations in certain months, but low nonsignificant correlations in other months. Reversal of correlation still occurred from month to month for some forest attributes.

Table 2.12 Correlation (R) of PAR to environmental attributes

	July 93	Aug 93
SDLT	-0.5983	-0.3548
SDST	-0.2136	-0.1784
SDHT	0.7358	0.2443
DBH	0.7612	0.3698
HT	0.7094	0.357
FDWM	-0.3395	-0.4174
CDWM	0.562	0.0022
# Stems	0.4984	0.6607
# BS	-0.3088	0.1166
% Grass	-0.6007	-0.4026
% Herbs	-0.109	-0.4002
% Shrubs	0.9025	0.7399
OM	0.4942	0.7261

The most highly correlated stand variables with PAR were the % shrub cover; and shrub stem abundance (Table 2.12). Grass cover was inversely related to light level. PAR values were strongly related to tree variables (height, BDH, SDHT and SDLT) in July 1993, but not in August 1993.

2.5 Discussion

2.5.1 Precipitation (rainfall and snowfall)

Over the longer-term, rainfall variations over the study area were small; however, short term precipitation differences were significant due to the highly localized nature of precipitation events. Short-term rainfall differences can be important if timed to phenological events, such as leaf expansion. Although precipitation variability did help explain some microclimatic discrepancies among stands; it did not explain differences among sites in the same stand or area. Canopy interception rates for the three age classes were not measured; therefore, it was not possible to determine if the vegetation interception created significant beneath-canopy precipitation differences among stands. Detailed precipitation measurements would be needed in order to assess this.

Trees affected the depth and the ablation of the snowpack, by increasing interception, slowing breezes and shading (Oke, 1989). Stems which were higher in younger stands would slow wind speed, thus minimize the potential for the redistribution of the snow (Oke, 1989). Stem surfaces warmed by the sun can act as thermal and radiating surfaces thus accelerating the melting of snow around the base of trunks. Variations between the three age classes were expected, because snow interception should increase as the size and number of large branches increased with age of the stand (McKay and Gray, 1981). Canopy gaps were zones of least snow catchment by the canopy, thus older stands with more and larger gaps were expected to have maximum snow depth at gaps in the canopy. In each age class of aspen forest, mean depth of snowpack was expected to differ.

In this study, snowpack mean depth did differ, because of the amount of snowfall rather than aspen stand characteristics. Old stands did have greater variation in snow depth than young and mature stands. This may be explained by the more undulating microtopography of the older sites, but differences in snowfall, due to regional variation, were a better explanation. Snow surveys were not sufficiently extensive to evaluate the impact of aspen age on snow cover characteristics. Over winter repeated, detailed snow surveys would have to be undertaken to determine if age of the aspen stand related to snowpack depth. Recorded annual variability of snowpack at Lac La Biche (Richardson, 1980) was much greater than variation measured within or between age classes, in this study. Therefore, snow surveys would best be done over several winter seasons to determine if spatial and temporal snowfall variability was more important than age class. Thunholm (1990) concluded that snowpack thermal conductivity was the most important property with regard to the insulating capability of the snow, which changed

considerably as the snow depth and density changed. Snowpack depth differences could explain why there were differences in soil temperatures among age classes.

2.5.2 Photosynthetically Active Radiation (PAR)

Temporal and spatial variations in light under a deciduous canopy can be significant (Hutchinson and Matt, 1977). Cloudy days would tend to minimize PAR differences between the age classes because of less direct sunlight (Young and Smith, 1982). In this experiment, it was observed that on cloudy days PAR was reduced to one-quarter of that of a sunny day. It was on sunny days that differences in PAR under the three age class canopies were more apparent. Ross et al., 1986 and Constabel, 1995 described maximum light levels before leaf expansion, after which light levels followed the solar cycle. In fall, light levels were expected to increase slightly when leaves abscised. Increased height and depth of the aspen canopy as well as large diameter trunks could be more efficient at shading during low solar angles in northern Alberta. The study results showed that foliage development reduced PAR by approximately one-third on sunny days in early spring. Following leaf expansion, light levels roughly followed the solar cycle until leaf drop. In autumn, light increased at the time of leaf senescence. Rauner (1976) found increased total and net radiation values beneath an oak canopy as the forest aged. Lieffers and Stadt (1993) measured a correlation between aspen stand age and PAR levels beneath an aspen canopy; however, this relationship was not observed in this study. The mature stands had the lowest light transmittance and old sites were the highest, but variations within an age class often exceeded differences among age classes. The amount of light beneath a forest canopy varied both spatially and temporally because of the forest structure. Most of these differences occurred within 5% of the instrumentation error. Only one point measurement at a site was made; this may have been insufficient to measure the variation of PAR levels under an aspen canopy. Lieffers and Stadt (1993) and Constabel (1995) measured PAR at numerous locations beneath aspen canopies of different ages and they found variations in these light levels. They also reported a strong correlation between tree basal area and light levels. In this study, tree density, DBH and height had a moderately strong correlation to PAR in July because of the foliage. Correlations in August were lower because of leaf senescence at the end of the month.

Canham et al. (1990) found that phenological development reduced radiation beneath a forest canopy and that PAR depended on the type of forest canopy. Height of canopy cover, a thinner canopy layer or gaps in the canopy were all important factors affecting light conditions beneath a forest canopy (Canham et al., 1990). Preliminary tree canopy

observations indicated that aspen canopies increased in both height and crown length with age of the stand. A shade-intolerant species, such as aspen, would rapidly self-prune lower foliage in response to insufficient light to support photosynthesis as the canopy grew in height (Goulet and Bellefleur, 1986). Therefore, light conditions beneath different-aged aspen canopies were expected to be relatively similar. Canopy photographs taken at 1.25 m had 15-24% open sky. Such a range of canopy closure for the three age groups produced similar PAR levels irrespective of canopy age, but photographic results indicated that the young stands had higher sky view values than the mature stands and had higher PAR values. However, young sites had a greater percentage of open sky than the old sites, but slightly lower measured light levels. Cloud conditions may have been significantly different between distal stands. The photographs were taken in late-August which in northern Alberta may be within the period of leaf colour change and fall. There was a 6% increase in the amount of open sky between a midsummer canopy photograph and a late-August photograph at the same point in an old site (O-1-5). Young successional species have been found to have higher light saturation curves than later successional species; thus, late successional taxa were more photosynthetically efficient at low light intensities than young successional taxa (Bazzaz, 1979). Other physiological differences between young and late succession species were also observed. Shade-intolerant aspen would be replaced by more shade-tolerant coniferous species, therefore, aspen understorey species would undergo some successional changes. Ross et al. (1986) recognized that changes in light have potentially important implications on phytochrome-control development and succession in species. In coniferous stands, increased light allowed for increased growth of herbaceous vegetation (Anderson, 1963). Increased shrub, forb and grass cover should mitigate any real increase in light reaching the forest floor. This trend was observed for shrubs, but not for either herbs or grasses. Vegetation survey results showed there were no significant change in species composition between age classes, only a change in species cover. Lieffers and Stadt (1993) found that shrub cover decreased with a decrease in light. In this study, PAR was found to correlate best with shrub cover. Number of shrub stems peaked in the oldest stands (117) and mature had the least (37). Young stands had an intermediate value (97) that also reflect levels of light. Herb and grass cover was more variable by site than by stand age, and was negatively related to light intensity. This response was observed by Lieffers and Stadt (1993) with the grass *Calamagrostis canadensis* and the forb *Epilobium angustifolium*. Both percent herb cover and grass cover did not correlate with PAR levels (Table 2.12) as highly as shrub cover perhaps due to shading of herbs and grasses by the shrub layer.

Light levels and other microclimate variables are not the only physical factors affecting forest composition or structure. Shrub and forb assemblages may have changed in response to other factors, such as soil conditions. For example, Crozier and Boerner (1984) found no significant correlation between light intensity and the abundance of a species. Other microhabitat factors (soil pH and nutrients) were shown to better explain the relative abundance of certain species (Crozier and Boerner, 1984). MacDonald and Lieffers (1993) observed less growth of *Calamagrostis canadensis* rhizomes in cooler, shaded treatments, but observed that treatments with competitive environments produced the least growth. Canopy changes such as opening of the tree canopy would cause less interception of precipitation, thus greater soil moisture or leaching of nutrients from the soil.

2.5.3 Wind

Wind conditions beneath a forest canopy are known to be much less severe than above the canopy surface. Oke (1989) stated that taller trees decreased wind speed more than shorter trees. Beneath aspen canopy wind speeds were reduced by 7-21% in comparison to above canopy wind speeds (Jones and DeByle, 1985). Maximum speeds were reduced the most, in both absolute and relative terms (Marston, 1956). Leafless trees can have significant effects on the wind and with leaves, the effects would be greater. Rauner (1976) noted that a secondary canopy strata of short trees or tall shrubs can farther reduce wind speeds and that greater tree stem density reduced air movement beneath a canopy.

In this study, young stands had the shortest trees, thus impose less resistance to airflow than do mature and old stands; therefore, maximum wind speeds and variations will occur in the younger stands. Mature stands, although taller than young stands, had less tall shrub cover to impede air movement below the tree canopy. Old stands were expected to have the slowest winds and the least variation in wind speed, because old stands had taller trees with greater canopy surface roughness. They also contained more tall shrub cover than either young or mature stands; therefore, old aspen stands would be most efficient in the inhibition of airflow beneath the canopy layer. Less wind turbulence resulted in less air mixing, thus permitting larger extremes in temperatures. Wind can also have a significant influence on the potential evapotranspiration rates (Skidmore et al., 1969).

Based on wind speed results from this study, it could not be concluded that age class affected wind velocities. Variability within an age group was greater than the variability between age classes. There were several other reasons that wind speeds did not correlate with age class. First, winds were gusty and they did not persist long enough

to be accurately measured by the anemometer. Second, anemometers were located too close to the plane at which wind speeds beneath a canopy approach zero values; the plane of zero displacement. Forest attributes of canopy heights and stem densities affected wind to such an extent that stand age was not a major consideration.

2.5.4 Temperature

Air temperatures did not vary significantly with age class, over time, but varied significantly from site-to-site. Herb cover and organic matter correlated best with air temperatures because these were the surfaces that, when struck by light, warmed and heated the air beneath the aspen canopy. Mueller-Dombois (1962) noted that temperature differences beneath jack pine ecosystems were due to tree and shrub strata, but recognized the potential of lower strata (i.e. forb and moss) to influence near ground temperatures in an ecosystem. It was observed that temperatures at -5 cm depth were more influenced, by forest attributes than other temperatures in the stands (Table 2.10). Soil temperatures correlated better to understorey plant (shrub, herb and grass) abundance and surface material (OM or FDWM) than to tree attributes. Hogg and Lieffers (1990) recognized, after logging, the impact that one common aspen forest grass species, *Calamagrostis canadensis*, had on the soil thermal regime after logging. Grass cover correlated to soil temperature better than either shrub or herb cover. Oke (1989) noted that ground cover (OM and FDWM) has greater insulation than live biomass. Organic matter slowed the warming on the soil in summer but would reduce cooling in fall.

Soil texture and structure, as well as surface colour and roughness affected soil temperature. Aspen does grow in a wide range of soil textures (clay to sand) and moisture levels (dry to moist). Soil moisture, structure and texture have a strong influence on aspen site quality. Steneker (1977) described the optimal soil texture (sandy loam to clay loam) and soil moisture (fresh to moist) regime for *Populus* growth. In this study, most of the microclimate site soils fall outside this ideal texture. Soil temperature had been found to be directly related to soil specific heat capacity, thermal conductivity, diffusivity and emissivity (Sellers, 1965). He asserted that temperature amplitudes depend on the texture of the soil (sand > loam > peat > clay), but that moisture content also had an extremely important influence on soil temperature. Unfortunately, in this study no soil moisture data were collected.

Strong and La Roi (1985) noted that more that 50% of aspen root growth was in the top 15 cm of the ground surface and mostly concentrated in the lower humus layer or just below it. Peterson et al. (1987) stated that there was a negative

correlation between humus thickness and soil temperature. Soil temperatures also depend on soil drainage and moisture levels (Davidoff and Silem, 1988, Thunholm, 1990). The sandy young site, in this study, was a much drier site than the silty young site. If moisture regimes varied considerably from site to site, this would explain the lack of consistency in temperature differences between age classes or sites within the same age class.

Deeper soil temperatures (-25 cm) correlated better to depth of organic matter content than did shallow temperatures because of where the shallower sensors were positioned within the organic layer. The -5 cm measurements correlate better than the -25 cm soil measurements to the type of material (FDWM) comprising the organic layer. Certain old stands did have significantly cooler soil temperatures than young or mature stands, but one site did not. These cooler conditions were expected because the insulating shrub cover and litter layer were thickest in the old sites. The soil temperature of the sandy site was more variable on a diurnal basis. Most of the soil temperature differences at -25 cm fell within the sensor error range. Age class temperature differences may be insignificant when compared with climatic records or predicted climate changes.

It should be noted that the forest attribute data in this study represents the site (collected within 100 m of plot centre) and may not exactly represent the specific site characteristics at the microclimate station. Monthly changes in the site characteristics and climatological conditions may explain the lack of a consistently strong correlation between these two factors.

2.6 Conclusions

Individual site microclimatological differences were greater than age class differences. Microclimate differences between sites were not always directly related to aspen forest age; other factors (understorey vegetation and organic matter) tended to dominate over microclimate influences. Additional environmental variables that needed to be correlated include regional climatic differences, soil thermal properties, site moisture regime, macro- and meso-topographic position of sites, ecological nutrient regimes and species insulating values. Increasing the number of observations, to greater than seven microclimate stations, should also clarify interrelationships between variables of the environment and the microclimate. Microclimate of aspen forests, regardless of age class, showed greater similarity than would be expected when compared with a non-forested or coniferous forest microclimate.

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Microclimate of an Aspen Forest, Edge and Cutblock

3.1 Introduction

Vegetation cover modifies the climate near the ground (Oke, 1987). It reduces insolation of the ground, slows wind movement because of aerodynamic drag, intercepts precipitation, acts as an insulation layer reducing temperature fluctuations and alters the water balance. Denser, deeper vegetation such as a coniferous forest cover has a greater affect than a thin sparse cover. Natural changes in forest structure, such as the annual leafall or a successional progression from a deciduous aspen to coniferous spruce forest, will result in changes in light, wind, humidity and temperature (Oke, 1989).

Keenan and Kimmins (1993) summarize the effects of clear-cutting on ecosystems (diversity and composition of flora and fauna), hydrology, nutrient cycling, soil and microclimate. Cutting changed the local hydrology by affecting water balance (evapotranspiration and surface runoff) and water quality (temperature, dissolved nutrients, turbidity and ecological processes). These directly altered nutrient cycling and soil fertility. Soil temperature and water content affect decomposition rates (Yin et al., 1989). One microclimatic parameter can affect other parameters. For example, less wind caused cooler minimum temperatures, increased frost events, and warmer maximum temperatures. Warmer ground had increased evaporation (Hungerford, 1980).

Keenan and Kimmins (1993) concluded that the effects of clear-cutting varied because of site conditions (climate, geology, soil, topography and biota) and harvest practices. Harvesting modified soil physical properties by compaction and increased erosion losses. They concluded forestry management can minimize environmental damage and change by using proper harvesting practices. They found unharvested buffer strips along stream courses reduced siltation and reduced temperature increase, both factors which are harmful to aquatic life.

Deforestation effects are both immediate and long term. A clearcut can increase soil temperature and moisture for 5 years (Meng et.al., 1995). Repeated cutting may alter the forest species composition and thus change the forest structure. Forest microclimate is affected by the forest attributes of height, shape, density, strata and stomatal control (Oke, 1989). These structural and microclimatic changes will directly affect wildlife habitat and biodiversity (Keenan and Kimmins, 1993).

Site revegetation depends on damage to understorey, detrital residue and intensity of harvesting. Type and extent of regrowth significantly affected the clearcut environment (Keenan and Kimmins, 1993). Microclimatic changes can release competition that inhibits reforestation. After logging in northern Alberta, Hogg and Lieffers (1991) found that

competition from a single species of grass (*Calamagrostis canadensis*) restricted aspen regeneration by affecting the soil thermal regime.

Management practices must ensure proper aspen regeneration for future harvests. Cutting an aspen forest promotes aspen suckering because of the release from apical hormonal dominance and warmer soil temperature (Peterson and Peterson, 1992). A threshold soil temperature of 15°C must be achieved for aspen suckering to occur. Suckering can rapidly re-establish a dense aspen canopy (Peterson and Peterson, 1992), thus minimize both short and long term shifts in microclimate.

Keenan and Kimmins (1993) define clear-cutting as the removal of the "forest influence" by harvesting of the trees. A clearcut is an area where the "forest influence" is mitigated and the clearcut environment dominates. The forest edge is the visual boundary between a forest and a cutblock; a zone where the "forest influence" and "cutblock influence" most intensely interact (Keenan and Kimmins, 1993).

Differences between these zones can be critical to plant and animal species survival. The three purposes of this study are: A) to measure and compare the effects of cutting aspen forests on the microclimate parameters PAR, wind and temperature; B) to assess whether the forest or cutblock microclimate has a greater influence at the forest-clearing boundary; C) to determine if an aspen cutblock can alter the microclimate in an adjacent forest.

3.2 Study Area

All sites were located east of Lac La Biche, Alberta, Canada (Figure 1.1). The three treatments were located within the same aspen stand. There were two replicates of each treatment which were less than 25 km apart at sites M42 and O26. Site O15 was selected to represent a forest site without an adjacent logged area.

3.3 Methods

Seven microclimate stations were located to monitor three treatments: aspen forest cutblock, cutblock-aspen forest edge and uncut aspen forest. Part of a Mature (M4) and Old (O2) stand (Plate 2.1 and 2.2), which previously contained microclimate stations (Chapter 2), were harvested in the winter of 1993-94. Two of the forest stations were located in the aspen forests adjacent to a cutblock (M4 and O2 respectively); one site (O1) represented a forest environment with no adjacent harvest block. Both microclimate stations from the Young stands, (Chapter 2), were relocated. One station was placed along the edge of a mature forest cutblock and the other along the edge of an old aspen forest that had

been cut. The border orientation was 60°N, with the aspen forest to the southeast (Plate 2.3). Forest and cutblock stations were located at least 200 m from the aspen forest edge. Residual trees or clumps existed in both cutblocks.

Microclimate stations, sensor arrays, sensor offsets, sensor accuracy and sampling were identical to procedures in Chapter 2. The only addition was the establishment of a rain gauge in each cutblock. All sensors were checked for calibration shifts.

Hemispherical photographs of the canopy cover were taken with a fish-eye lens (180°) at the location of each quantum sensor, in August. Percent canopy cover was calculated from these images using an optical scanner.

Plate 3.1 Mature aspen stand that has been harvested.

Plate 3.2 Old aspen stand that has been harvested.

Plate 3.3 Forest edge site in an old aspen stand

Figure 3.1

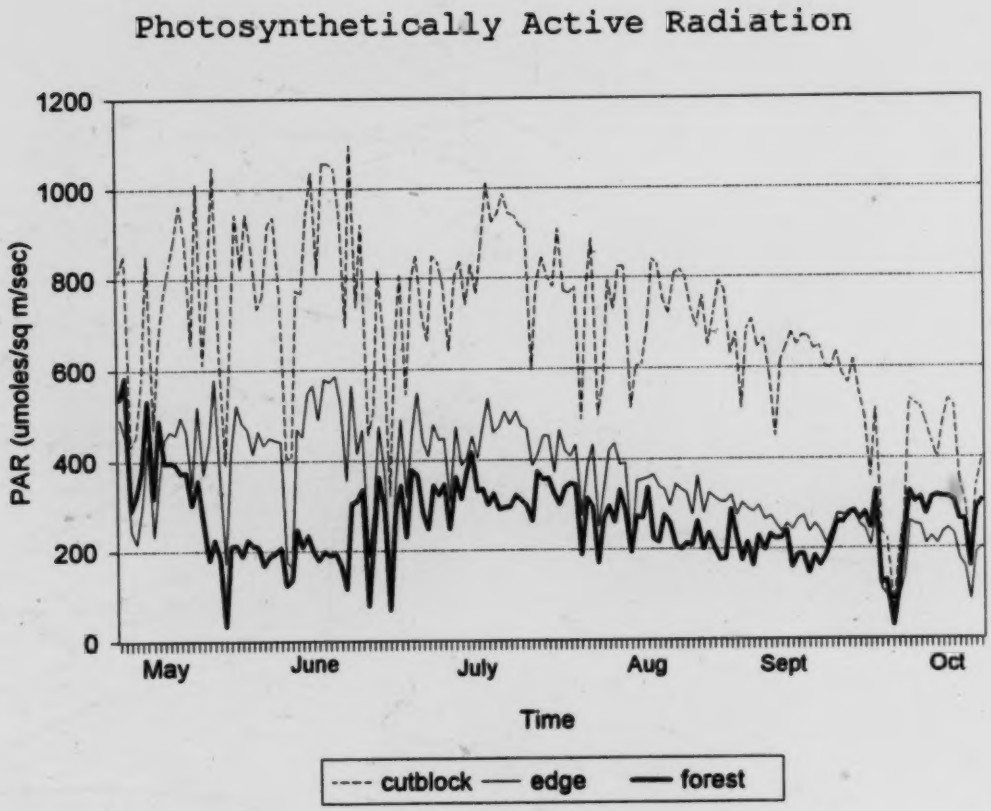

Photosynthetically Active Radiation
1200
1000
800
600
400
200
0
PAR (umoles/sq m/sec)
May
June
July
Aug
Sept
Oct
Time
---- cutblock — edge — forest

Figure 3.2

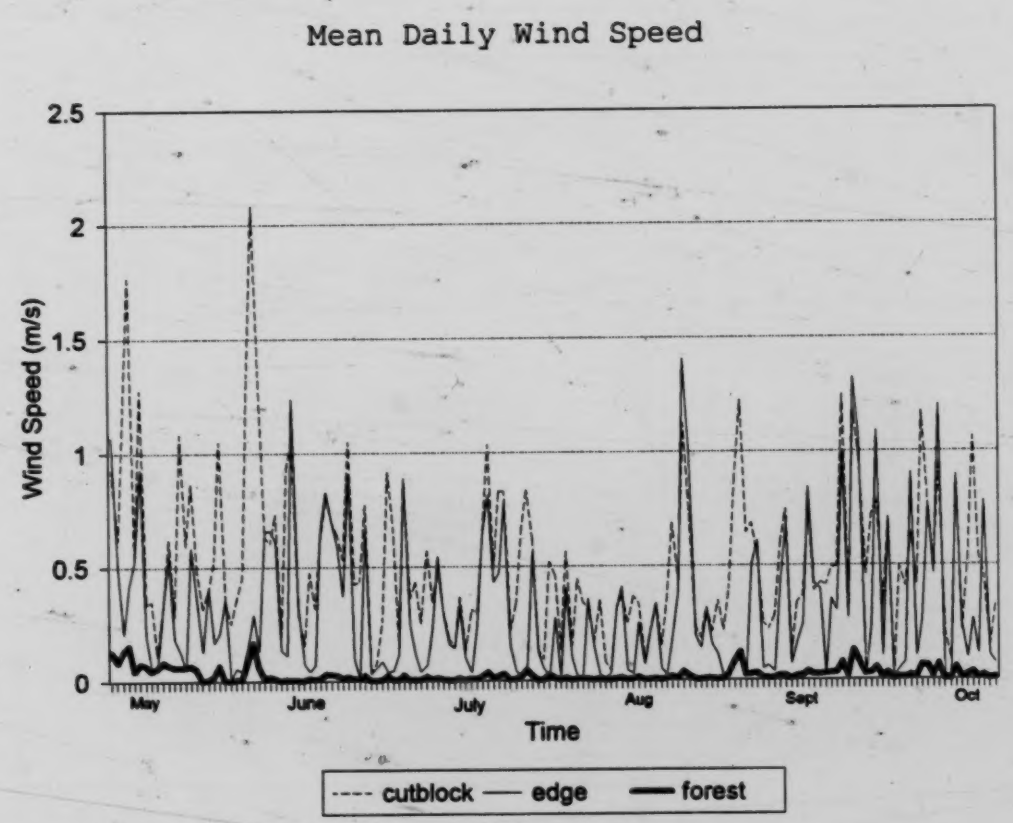

Mean Daily Wind Speed
Wind Speed (m/s)
2.5
2
1.5
1
0.5
0
May
June
July
Aug
Sept
Oct
Time
cutblock
edge
forest

Figure 3.3

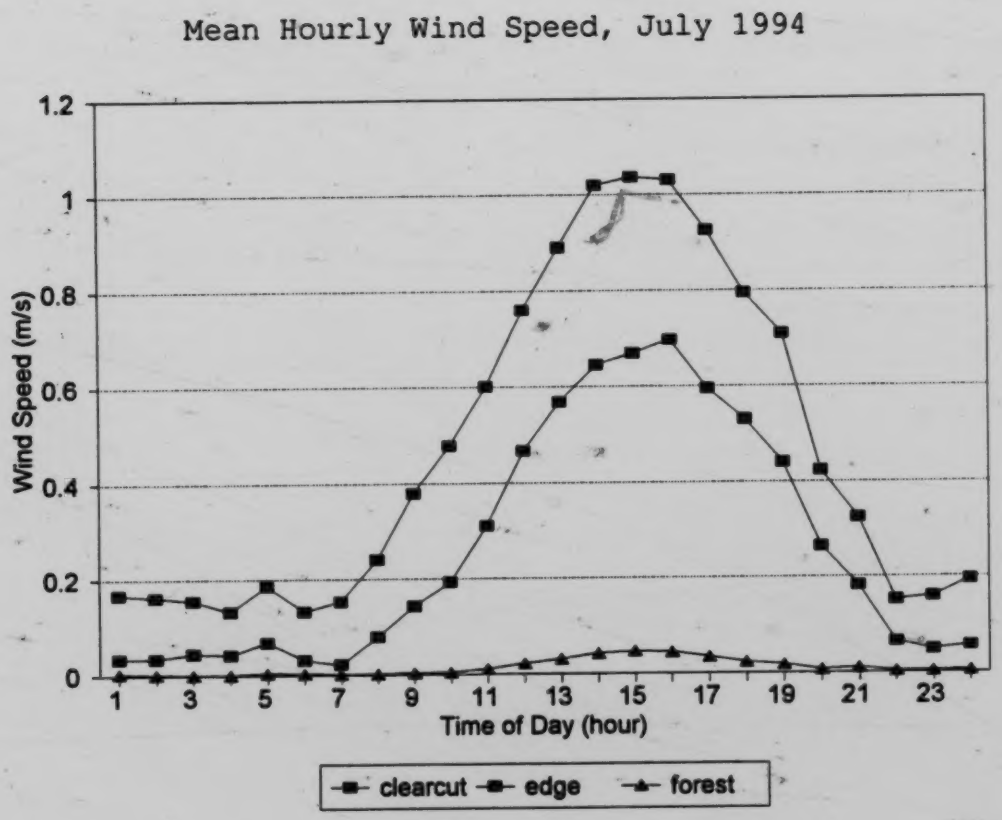

Mean Hourly Wind Speed, July 1994
Wind Speed (m/s)
1.2
1
0.8
0.6
0.4
0.2
0
1
3
5
7
9
11
13
15
17
19
21
23
Time of Day (hour)
clearcut
edge
forest

Figure 3.4

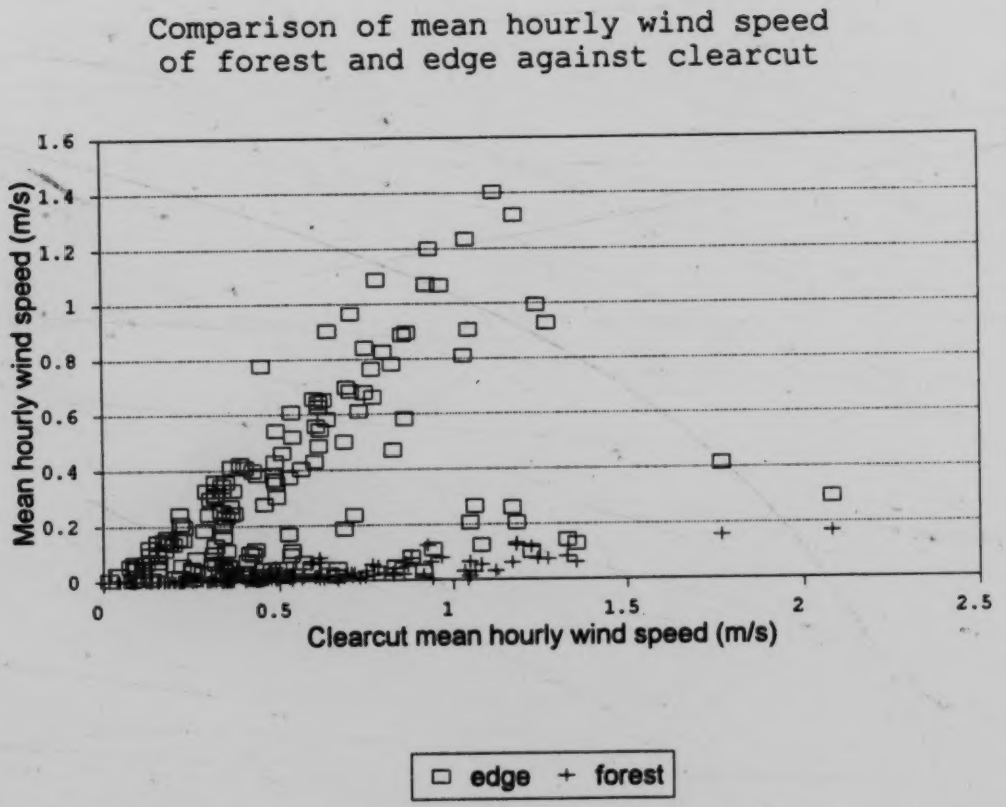

Comparison of mean hourly wind speed
of forest and edge against clearcut
Mean hourly wind speed (m/s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
Clearcut mean hourly wind speed (m/s)
edge
forest

Figure 3.5

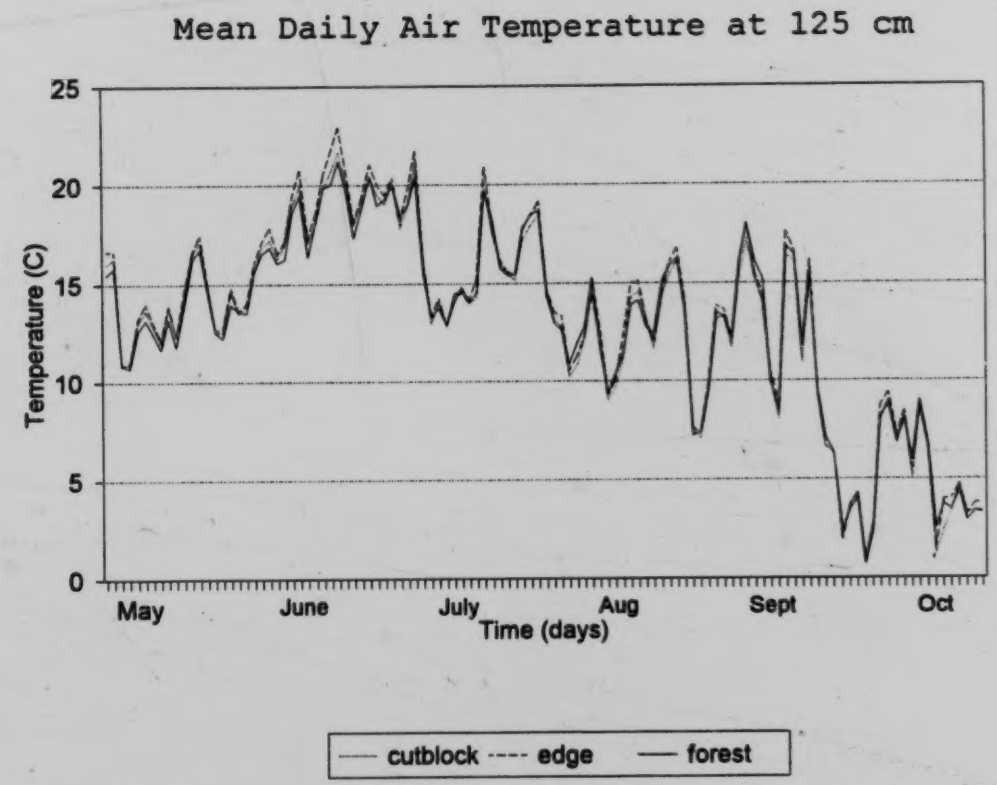

Mean Daily Air Temperature at 125 cm
Temperature (C)
25
20
15
10
5
0
May
June
July
Aug
Sept
Oct
Time (days)
cutblock
edge
forest

Figure 3.6

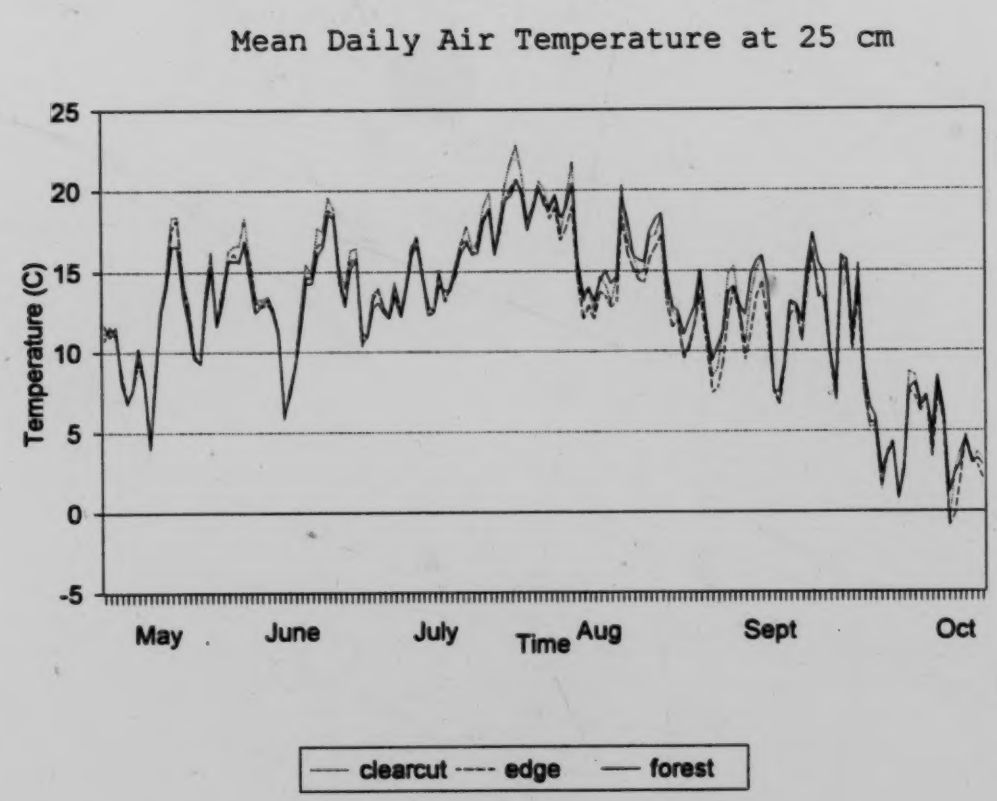

Mean Daily Air Temperature at 25 cm
Temperature (C)
25
20
15
10
5
0
-5
May
June
July
Aug
Sept
Oct
Time
clearcut
edge
forest

Figure 3.7

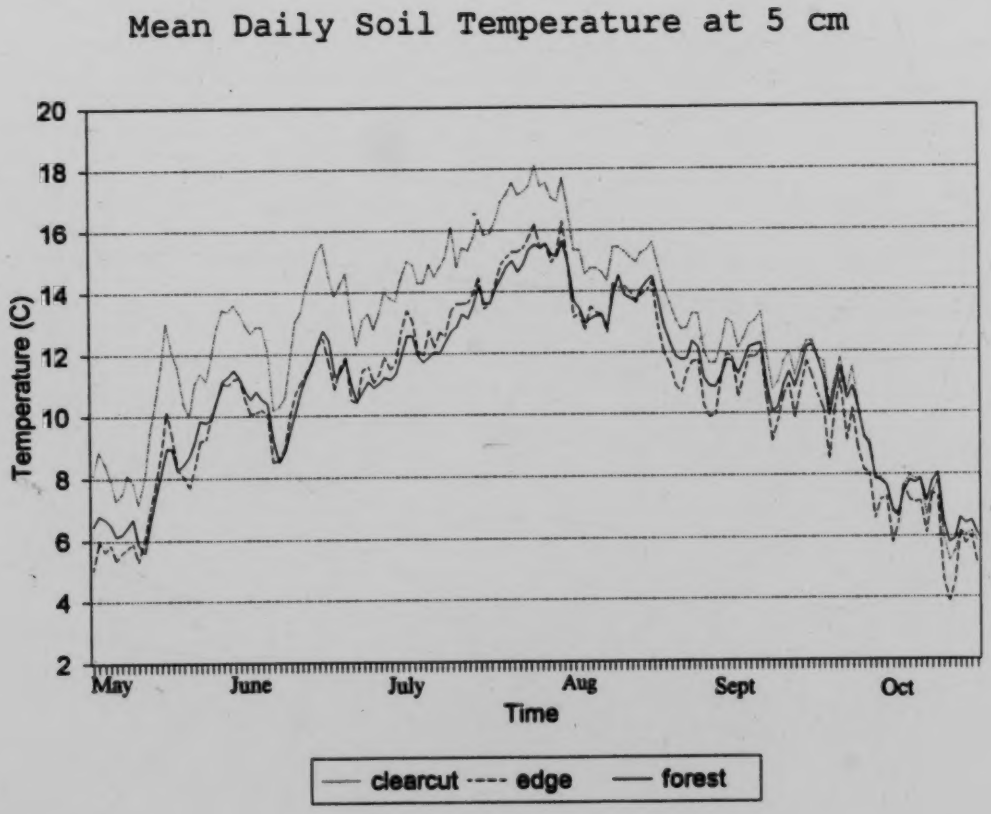

Mean Daily Soil Temperature at 5 cm
Temperature (C)
20
18
16
14
12
10
8
6
4
2
May
June
July
Aug
Sept
Oct
Time
clearcut
edge
forest

Figure 3.8

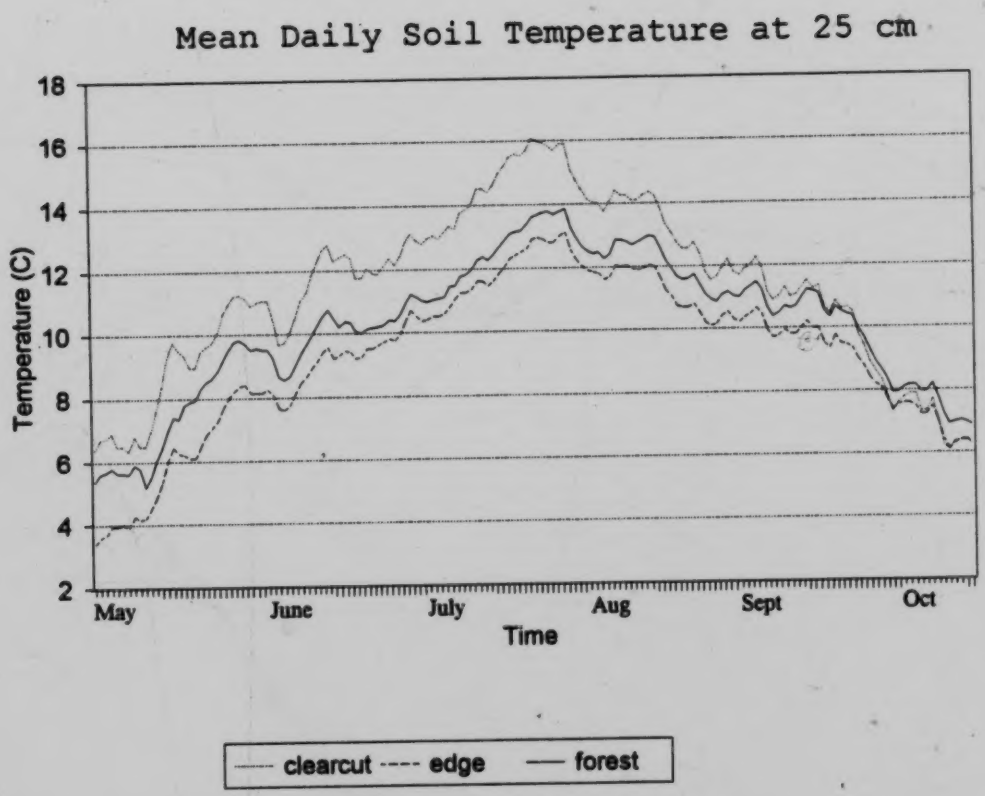
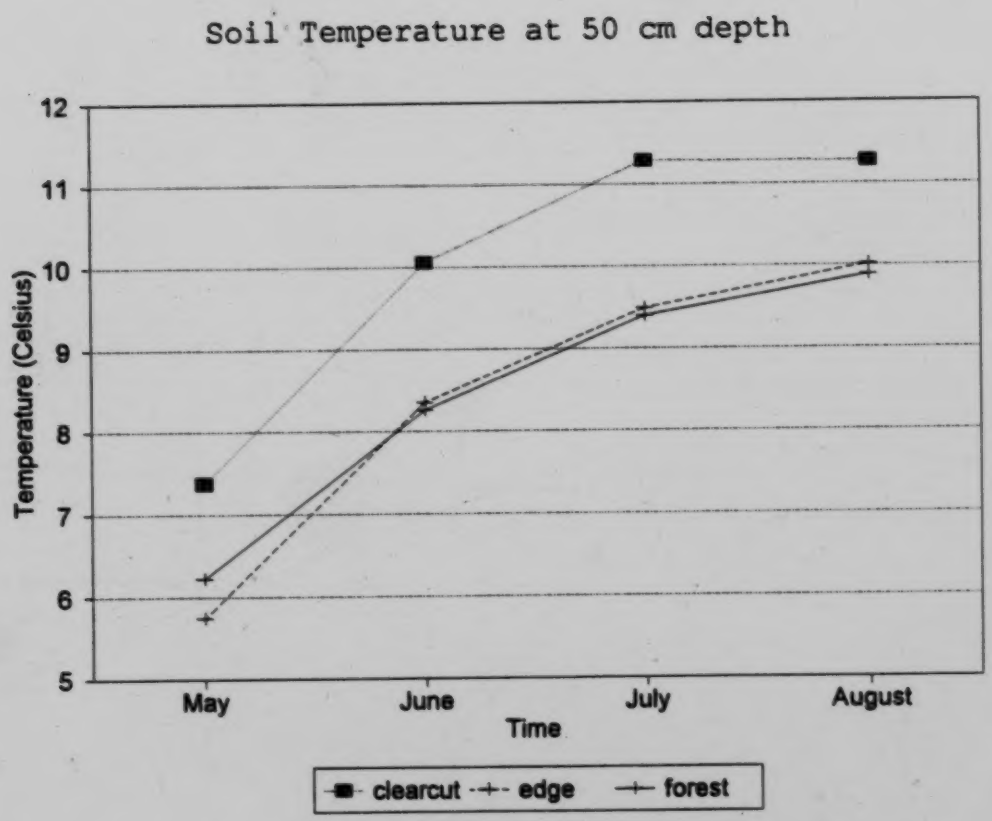

Mean Daily Soil Temperature at 25 cm
Temperature (C)
18
16
14
12
10
8
6
4
2
May
June
July
Aug
Sept
Oct
Time
clearcut
edge
forest

Figure 3.9


Soil Temperature at 50 cm depth
12
11
10
9
8
7
6
5
Temperature (Celsius)
May
June
July
August
Time
clearcut
edge
forest

3.4 Results

3.4.1 Data Analysis

Data were pooled to test treatment differences. Site-to-site comparisons were made to determine if the significant differences between treatments was caused by just one site. Comparisons were done on hourly, monthly and seasonal intervals to examine short and long term variability. Daily temperature averages and standard deviations were calculated and compared (t-test) for the treatments. Daily temperature ranges were examined using one-way ANOVA and Tukey-HSD test using the statistical package SPSS 6.0, 1993. Rainfall was examined to determine if precipitation variation could explain radiation, wind, or temperature differences among stations.

3.4.2 Precipitation

For the three treatments, total precipitation varied over the summer by less than 9%, but over a shorter interval, rainfall amounts did vary by more than 50%. Localized thunderstorms can account for precipitation differences which also affected short term (hourly) changes in PAR, wind and temperature.

3.4.3 Photosynthetically Active Radiation

Maximum PAR differences between the cutblock and aspen forest occurred (June-July) near summer solstice when the aspen canopy transmitted only 38% of PAR, (Figure 3.1, Table 3.1). Forest and forest edge PAR decreased only slightly in May because of leaf expansion. In autumn, the low solar angle mitigated PAR differences among treatments. Thick cloud cover also eliminated PAR differences while partial or thin cloud cover reduced PAR by approximately one-quarter. Harvesting had much greater fluctuations in PAR from day to day and hour to hour than the other treatments. In autumn, the PAR was less at the forest edge than in the forest, but not significantly ($P<0.05$).

Residual trees near one of the cutblock stations (M4) had a major effect on incoming radiation. In July, they reduced radiation by less than 50% when compared to the other cutblock (O2) with no shade-generating residual trees. When the completely cleared site (O2) was used for comparison, it was evident that the aspen canopy reduced PAR to approximately 78% of that in full sunlight.

The degree of open sky, measured from the spherical canopy photographs, was correlated against PAR values (August $r^2=0.731$) for the three treatments. Forest PAR values were most correled to canopy openness (August $r^2=0.941$) because of clustered data.

3.4.4 Wind

Average wind velocities beneath an aspen canopy were 50 times greater in the cutblock than the forest and 30 times greater at the forest edge (Figure 3.2, Table 3.1). Occasionally wind speeds were greater at the forest edge because of the greater fetch associated with wind from the northwest direction. Maximum daily average wind velocities were 12 times greater in the cutblock than the forest and 8.5 times greater in the cutblock than at the edge.

Table 3.1 Mean daily soil and air temperature, wind and PAR

	Month	Cutblock	Edge	Forest	F ratio
Temperature (°C) 125 cm	July	16.5±2.8	16.9±3.1	16.1±2.8	0.56*
Temperature (°C) 25 cm	July	16.6±3.0	16.2±2.6	16.1±2.6	0.70*
Temperature (°C) -5 cm	July	15.4±1.4	13.4±1.4	13.0±1.4	6.75
Temperature (°C) -25 cm	July	13.7±1.3	10.9±1.0	11.6±1.0	7.13
PAR (umol $m^{-2}s^{-1}$)	July	1588±284	865±154	626±122	17.3
Wind ($m\ s^{-1}$)	July	11.2±6.2	6.2±6.0	0.2±0.3	9.89

t-test of daily mean of cutblock versus aspen forest
*-not significant ($P<0.05$)

The few residual aspen trees in the one cutblock reduced wind speed. Average daily wind speed in the cleared block was more than twice as fast as in the harvest block that had residual trees. There was no significant difference in wind speed among the forest stands.

Only in the forest did the minimum daily average wind speed drop to zero; whereas, the cutblock minimum speeds were twice that at the forest edge. In July, forest sites were calm 69%, edge 39% and cutblocks 15% of the time. When vegetation was leafless (Oct.) forest sites were calm 40%, the edge 26% and the cutblock 10% of the time. Winds in forested sites were not significantly different; furthermore, a cutblock adjacent to the aspen forest did not affect airflow 200 m into the forest stand.

All sites displayed a strong diurnal change in wind speed with a maximum occurring mid-afternoon with calmer conditions at night (Figure 3.3). Daily warming of the landscape by the

sun produced surface warming that led to thermal instabilities and strong convective cell development. The cutblock had the greatest diurnal amplitude in wind followed by the forest edge while the forest had minimal diurnal increase. Wind speeds at the three forest sites were not significantly different and were often less than the anemometer threshold speed.

The cutblock wind speeds correlated with the forest velocities (R^2=0.6965) thus reflecting the strong regional air mass movements. The forest edge wind speeds were poorly correlated to those of the cutblock (R^2=0.268) or the forest (R^2=0.0634). The wind speeds at the forest edge had a dual pattern (Figure 3.4).

3.4.5 Air Temperature

Mean daily air temperature (MDAT) at 125 cm and 25 cm was not significantly different among the treatments or sites over the summer, (Figure 3.5 and Figure 3.6). In July, maximum daily average temperature was 1.7°C greater in the cutblock than the forest, indicative of calm, sunny days. Minimum MDAT were within 0.2°C, this was representative of cool, rainy days.

Table 3.2 Mean diurnal air temperature range (±S.D.)

Height (cm)	Month	Cutblock	Forest Edge	Forest	F ratio
125	May	13.2±4.8	13.4±4.7	12.6±4.3	0.5*
125	June	11.4±4.6	11.7±4.8	9.1±3.7	6.7
125	July	12.3±3.9	12.4±3.8	9.7±2.8	15.2
125	Aug	14.6±3.2	14.3±3.0	11.2±2.5	34.2
125	Sept	14.7±5.0	14.5±4.9	11.3±3.9	10.2
125	Oct	9.7±5.6	9.6±5.3	8.1±4.2	1.4*
25	May	16.6±6.1	17.4±6.0	15.3±5.5	2.2*
25	June	15.2±6.1	15.6±6.2	9.5±3.9	24.3
25	July	16.7±4.9	16.3±4.8	9.8±2.7	71.4
25	Aug	19.8±3.8	17.5±3.9	11.7±2.9	110.9
25	Sept	19.8±5.7	17.7±5.6	12.6±3.9	41.1
25	Oct	12.5±7.3	12.3±6.4	9.7±4.9	2.9*

Anova test and Tukey-HSD test of daily temperature range ($P<0.05$), * - not significant

Daily fluctuations in air temperature were not significantly different, for the three treatments, when (May and October) plants were leafless (Table 3.2). When foliage was present (June-Sept), daily range in temperature was different. Diurnal thermal fluctuations were similar in the cutblock and forest edge treatments, but both differed from the more stable forest environment. For August, all three treatments had significantly different ranges in air temperature at 25 cm.

3.4.6 Soil Temperature

Air temperature at 125 cm or 25 cm were not a good indicator of the soil thermal regime. Mean daily soil temperature (MDST) at -5 cm was more than 1.5°C cooler in the forest and edge than the cutblock (Figure 3.7). The forest edge was only 0.2°C cooler than the forest. Most of the thermal difference was established in spring between snow melt and leaf emergence. Maximum MDST occurred in the cutblock (18.1°C) with edge (16.3oC) intermediate and the forest the coolest (15.3°C). Minimum MDST occurred at the forest edge (3.9°C) with the forest cooling less (5.6°C) and the cutblock being similar (5.2°C). Mean daily soil temperature (MDST) at -25 cm paralleled the observed patterns at -5 cm (Figure 3.8). Rapid warming of the ground in early spring was again a predominate feature as was a rapid decrease in Autumn. In the cutblock area deeper soil temperatures (-50 cm) were also significantly influenced by aspen harvesting (Figure 3.9).

Table 3.3 Mean diurnal soil temperature range (S.D.) at 5 cm

Month	Cutblock	Forest Edge	Forest	F ratio
May	4.3±2.2	4.8±2.9	2.2±1.4	26
June	4.6±2.4	4.7±2.7	1.4±0.5	51
July	4.9±1.9	3.6±1.1	1.4±0.6	126
August	5.2±2.2	3.3±0.8	1.7±0.7	137
Sept	4.7±1.9	3.1±1.0	1.6±0.7	113
Oct	2.5±1.3	1.6±0.7	1.0±0.5	36

* all are significantly different

Comparison of the three forest sites showed no differences attributable to an adjacent cutblock. Forest influence dominated that of the cutblock at the forest edge based on the fact that mean daily soil temperatures at the edge were more similar to forest soil values compared to the

clearing.

At 5 cm depth, the daily ranges in the soil temperature were significantly different for the three treatments (Table 3.3). Diurnal fluctuations at 25 cm were not significantly different. At the forest edge, daily soil temperature oscillations were intermediate between the forest and cutblock.

3.5 Discussion

3.5.1 Water Balance

In this study, based on casual observations at the sites, snow depths were not different at the three treatments. This could be explained by the disturbance of the snowpack during harvesting in the winter. However, other studies have found that cutting does influence snow depths by affecting accumulation and redistribution. Berndt (1965) found that snow accumulation on the ground was greater in cutblocks than in forests because of less interception by the lodgepole pine canopy. Meng, et al, (1995) found that clearcutting had a negative impact on the water balance of a harvested basin due to less snow and fog catchment by trees. Kershaw (1991) found the prevailing wind redistributed snow from a clearing to a forest edge.

It was expected that harvesting of the study stands would result in an increase in precipitation reaching the ground because of less canopy interception (Oke, 1989). After a coniferous forest was harvested, precipitation received at the ground surface increased 15-50% (Keeman and Kimmins, 1993). Johnston (1971) estimated that interception by aspen and understorey herbaceous vegetation was only 10.3% of gross summer rainfall; therefore, he concluded that the removal of aspen trees would not greatly reduce rainfall interception or increase soil moisture.

Based on field observations at the study sites, the ground surface in the cutblock was perceived to be dryer than the forest floor. The ground surface was efficiently dried by the increased insolation, warmer soil temperature and greater airflow in the cutblock compared to the forest. Using air temperature and wind speed data for the aspen cutblock and aspen forest in this study, potential evapotranspiration (PE) was estimated to be 2-8 times greater in the clearing than in the forest (Skidmore et. al, 1969). Increased evaporation losses could offset any reduction in transpiration caused by logging. Keeman and Kimmins (1993) and Meng, et al, (1995) found that clearcutting had a positive effect on the water balance of a harvested area because of a large reduction in evapotranspiration (ET). McCaughey (1989) found that the clearcut actual ET rate was related to water availability but the ET rate in forests was influenced by the vapour pressure deficit and wind speed.

After harvesting, the aspen suckering in a clearcut, could potentially have increased transpiration again and reduced evaporation rates. Surface cover type did affect rate of water loss (Lafleur and Schreader, 1994). Johnston (1970) found that an aspen tree cover or a herbaceous cover increased evapotranspiration (ET) compared to a bare ground surface.

3.5.2 Photosynthetically Active Radiation

On the study sites it was found that only 23-38% of PAR was transmitted through the aspen canopy. Constable and Lieffers (1996) reported that PAR decreased approximately 3 fold at 1.5 m, 5-9 times at 0.5 m and more than 16 times at ground level, under an aspen canopy. They sampled at midday on sunny days; this may explain their higher attenuation rates. Change in the radiation balance (net radiation, short wave, longwave and PAR) are directly related to the trees' ability to impede light penetration in the PAR range through absorption and albedo (Oke, 1989). Harvesting of a coniferous forest can increase shortwave radiation 10-20 times and decrease net radiation by half at the ground surface on a sunny day (Keenan and Kimmins, 1993). In a conifer stand, a 81% canopy density reduced PAR measurements by 95% (Fowler and Anderson, 1987). Keenan and Kimmins (1993) found that longwave also increased due to opening of the canopy and thus net radiation did not increase significantly.

At the cutblock treatment sites, some of the pre-harvest understorey plants appeared stressed in the open terrain. The cutblock treatments would be a harsher environment than beneath an aspen canopy because of the higher insolation, temperature and wind. These would affect plant survival and regeneration thus revegetation of the disturbance sites. Keeman and Kimmins (1993) noted that understorey plants intolerant to direct sunlight suffered after clear-cutting because of heat and water stress. Greenway (1995) found certain understorey plants displayed a limited photosynthetic rate that restricted their growth and expansion beneath a canopy but enabled them to survive the low understorey light conditions. These species were able to effectively exploit a post-fire environment and potentially a post-harvest environment. Plants with mechanisms to survive a harvesting disturbance will thrive after a clearcut. A species, such as aspen or some grasses, that rely on sub-terrain reproductive structures to vegetatively regenerate, will thrive in the new open environment. Leaf area index should increase with canopy closure and understorey growth to reduce PAR at the ground surface

At the study sites, plant cover (< 1.5 m height) was 20% (site O2) and 30% (site M4) for the two cutblocks. Aspen suckering cover was 15% and 25% respectively. The site with the greatest cover had no residual trees. At the edge, there was less than 3% aspen regeneration but over 40% plant cover.

Harvesting removed not only the aspen tree canopy but damaged the understorey plant cover. Peterson and Peterson (1992) found that the degree of suckering depends on how much of the overstorey is removed. Low to moderate cutting was insufficient to insure adequate aspen regeneration because aspen is a shade intolerant species. Almost full sunlight was required to produced a uniform and vigourous suckering. Even a few residual trees impeded suckering; at 50% of total sunlight, aspen suckering was reduced in size and numbers (only 6%) compared to a clearcut (Jones and DeByle, 1985). At the experimental cutblock sites it appeared to this observer that aspen suckers thrived after cutting with long stem elongation and large, thick leaves. In a few years, because of the high density of suckers, a closed canopy should develop. It will reduce light to a level comparable to pre-harvest levels as measured by Constable and Lieffers (1996).

The low correlation of canopy openness (estimated from photographs) against measured PAR values was caused by the orientation of the forest edge border and the position of tree stems or canopy gaps. Reifsnynder et. al. (1971) found that the relationship of PAR and canopy openness was not necessarily linear because of heterogeneity of the canopy.

3.5.3 Wind

Logging increased wind speeds and decreased calm periods, in this experiment. Results also indicated that faster winds are slowed more by vegetation than a light breeze. Leafless trees appeared to reduce wind but less than trees in foliage. Greater variation in wind speed between the two cutblocks could be explained by residual aspen and spruce trees that would slow airflow and enhance turbulence. Greater fetch and less resistance in the clearing accounted for windier conditions and faster wind speeds (Oke, 1989). Marston (1956), Jones and DeByle, (1985) reported wind speed in a forest averaged 7-16% those in a clearing. Ghuman (1987) also noted that after leaffall, wind speed increased in the forest, but was still significantly less than in a clearing. Reifsnyder (1955) found faster winds were reduced more than light winds and wind speed was reduced by 20% at the forest edge. At one of the cutblock sites (M4), the shallow rooted white spruce were all toppled by autumn. Faster winds and greater fetch in the clearcut can cause increased windthrow (Moore, 1977). Aspen trees, in the cutblocks, were neither up-rooted or snapped by the stronger winds. Aspens are relatively windfirm but root rot and heartrot make aging aspen increasingly susceptible to blowdown (Jones and DeByle, 1985).

In the experiment, mean wind speed at the edge was 54% of that on the cutblock but ranged from 0% to greater than 100% depending on wind direction. Correlation between measured open/canopy speeds was higher than Marston (1956) because forest wind velocities were frequently below the anemometer

threshold. Lack of a strong correlation of edge to forest or clearing as well as the dual pattern could be explained by wind direction. If the wind blew from the cutblock to the edge, edge speed correlated best to the cutblock speed. When the wind blew from the forest to the cutblock edge, the speeds were highly correlated.

No increase in wind velocities was measured, whether the aspen forest was adjacent to a cutblock or not. Aspen stems and understorey offered sufficient drag to slow the winds. Raynor (1971) found wind penetrated only 60 m into a coniferous forest.

Both diurnal and seasonal changes in the wind speeds were noticed at the study sites. Daily warming of the ground surface and development of thermal instabilities would explain the diurnal wind cycle. Regional winds appeared stronger in spring and fall because of reduced surface drag from the defoliated aspen canopy (Oke, 1989).

Spring soil temperatures at the edge were warmer than the forest but cooler than the clearing. The amount of insolation at each treatment can explain the warmer temperatures. Greater insolation caused earlier ablation of the insulating snowpack and greater warming of the soil in spring.

In the cutblock treatment, the increased turbulence will more efficiently remove warm air and water vapour from the near ground surface. With greater loss of thermal and latent heat from the surface, soil temperatures will be cooled. This could minimize air and soil temperature differences between the cutblock and forest treatments.

3.5.4 Air Temperature

Surface temperature heavily influences the temperature of the air above it (Oke, 1989). The surface-air interface is where radiant energy is received and dissipated by re-radiation, conduction, convection and transpiration/ evaporation. The surface can be surface water, soil or vegetation, each with its own unique properties (diffusivity, heat capacity, thermal conductivity, etc.). In the forest, the surface is the tree and understorey canopies. In the cutblock, it will be the ground surface, woody debris, remnant tree and understorey herb layer vegetation. The cutblock surface will receive, reflect and re-emit more radiant energy than beneath a forest canopy. Logging will increase both short and longwave radiant energy striking the ground; therefore, warmer soil temperatures will occur. A warmer ground will irradiate more energy, based on the Stefan-Boltzmann Law. Loss of vegetation cover will also increase radiation reflected from the surface. Because a cutblock has a higher albedo, the surface will reflect more incoming radiation, both shortwave and longwave. Because aspen harvesting changes the air-surface interface so dramatically, it is expected that significant changes will occur to the

radiation, albedo, evaporation, transpiration and convection. All of these affect temperature.

Mean daily air temperature at both 25 cm and 125 cm was similar at all the treatments for this study. Nesdoly and Van Rees (1994) reported similar results from an aspen study. Lack of a thermal gradient as evident by similar hourly air temperatures at 125 cm and 25 cm heights indicate efficient air mixing in all treatments. Other research found clearcuts were warmer by 2-5°C, but these involved dense coniferous forests (Keenan and Kimmins, 1993). With the removal of the aspen trees, airflow resistance would decrease, resulting in an increase in wind speed and turbulence. This would minimize thermal gradients in the air column developing over the ground surface thus accelerating both thermal and latent losses (Oke, 1989). Aspen tree branches do not interdigitate and are open beneath the main canopy; thus they offer less restriction to airflow than does a coniferous canopy. Air movement could effectively eliminate any thermal differences in the three treatments. Raynor (1971) found that the temperature profile beneath a coniferous forest canopy during the day (at 1.75 m) was about the same in the forest and clearcut, indicating similar warming rates. Regional air mass temperatures had a dominating effect on the microclimate environment.

Although similar daily means could be explained by airflow, this did not explain the significant variation on a daily basis. Daily temperature extremes were significantly different when foliage was present at the research sites, with forest fluctuations being less. Keeman and Kimmins (1993) noted that other studies had found much greater range in daily air temperature. In a clearcut, diurnal air temperature ranges were double at 1.5 m and 2.5-3 times greater at the ground surface. Direct solar input raised the maximum air temperatures 3-5°C at 1.5 m and up to 10°C at seedling height (Fowler and Anderson, 1987). Forest biomass (large surface area) absorption of thermal energy in the day and releasing it at night reduced diurnal fluctuations (McCaughey, 1989). Each of the multiple layers of the aspen forest (Lee et.al., 1995) modified the microclimate by reducing radiation inputs and outputs, retarding airflow, and evapotranspiration (latent heat) losses.

No further aspen suckering was observed at the experimental sites after August; aspen leaf expansion was also at a maximum. With the development of a vegetation strata (air-surface interface) between 125 cm and 25 cm, a difference in the daily range of air temperature developed for all sites. With the rapid regeneration of the closed aspen canopy (Peterson and Peterson, 1992), the post-harvest subcanopy microclimate should quickly be re-established.

Warmer air from the clearing would readily move because of the greater airflow to the adjacent cooler forest. Much of the insulating value of the vegetation was also lost at the

forest edge. Edge thermal fluctuations were similar to the cutblock. The cutblock had greater solar radiation input and re-radiation losses compared to the forest. The forest edge, with a northwest exposure, received 45.5% of the solar radiation compared to the cutblock and should have re-radiated approximately the same proportion.

3.5.5 Soil Temperature

At the cut experimental sites, a layer of medium and fine branch material was deposited. This detrital material could negate or buffer the effect of the disturbance. Wood is a good insulator and holds moisture for some time (Sellers, 1965). Harvesting alters not only the air-ground interface by removing the vegetation but alters the soil thermal properties by compacting or disturbing the organic mat (Spittlehouse and Stathers, 1990). Most energy transfer will occur at the ground surface after logging operations (Sellers, 1965). Ground surface conditions affected the surface temperature more than soil temperature just below (ie. 5 cm) the surface, because of the heat flow properties (thermal capacity, diffusivity, emissivity and conductivity).

A strong difference in temperature between air (25 cm) and soil (-5 cm) indicated the location of the thermal active interface. The active surface(s) were much closer to the ground in the cutblock and forest edge but farther from the ground in the forest. The energy interface surface in the cutblock was predominately the ground surface but was the canopy and understorey surface in the forest. Based on the soil thermal gradient, the cutblock and edge warmed at a faster rate than forest soil early in the growing season, with the clearing warming faster than the forest boundary. This trend was reversed in fall. Fowler and Anderson (1987) determined that in the clearcut maximum heating took place at the soil-air interface as evident by a decrease in temperature from the surface. In the forest, warming occurred throughout the understorey volume, as determined from the fact that the maximum air temperature occurred between 0.3 and 1.3 m above the ground surface. They also found that the diurnal temperature wave decreased with distance from the ground surface. Their greatest soil temperature variation, both spatial and temporal, occurred in the clearcut. In autumn, soil cooling was significantly greater in the open terrain compared to the poplar or white spruce forest.

Experimental results showed soils in the forest and at the forest edge were less than 2°C cooler than the harvested treatment. The increase in soil temperature at all depths was less than other studies (Keenan and Kimmins, 1993). Childs et. al. (1985) found clearcut soils 6°C warmer than shelterwoods at 2 cm. Fowler and Anderson (1987) measured increased soil temperatures in a clearcut of 7.7°C and 2.4°C at

a depth of 3.5 cm and 25 cm respectively. Their study involved white spruce with a thicker organic layer. At 50 cm, forest soils can still be 5°C cooler than disturbed sites (Keeman and Kimmins, 1993). Jeffery (1963) measured soil temperatures at 30 cm that were only 2.4°C (July) warmer in a clearcut compared to a balsam poplar stand. Disturbance of the organic layer was found to be critical to soil temperature changes. Hayhoe and Tarnocai (1993) found disturbing the vegetation and organic horizon increased depth of thaw in the permafrost and raised ground temperatures as much as 3.9°C at 150 cm depth. The degree of disturbance to the vegetation and soil affect the degree of soil temperature change (Evans et. al., 1988). Long term effects of clearcuts on soil temperature can be measured years later (Keenan and Kimmins, 1993). Dyrness et. al. (1988) found many of the understorey plant species survived logging and that soil temperature at 10 cm depth was twice that of an undisturbed control site. The type of disturbance (fire, harvesting, trenching) and intensity of the disturbance controls the depth of the effects. In a cutblock, mowing disturbances of the forb/grass layer increased mean soil temperature (10 cm) from May-August, by 3.8°C. Diurnal soil temperature variation increased 3-4 fold because of mowing. This demonstrates that the lower ground cover has a stronger impact than canopy removal. It was determined that standing dead and litter offered better insulation than some types of living biomass (Hogg and Lieffers, 1991).

The forest edge in the study did not get as warm as the cutblock, because it received less shortwave radiation (45.5%). It also re-radiated less energy than in the cutblock. There was less disturbance of the vegetation and organic mat at the cutblock edge and this could explain its similarity to the forest. Growth of aspen suckers and understorey also buffered the soil temperatures.

At 5 cm depth, soil temperature fluctuations on a daily basis were found to be significantly different for the cutblock compared to the aspen stand in this study. Both the cutblock and the edge treatments had daily ranges twice that observed in the forest soils. Keeman and Kimmins (1993) reported that, the maximum daily surface temperature can be as high as 30°C warmer in the clearcut, on a sunny calm day. They cautioned that such extreme temperatures can reduce photosynthesis, damage plant tissue or even be lethal to young seedlings. At night, Keeman and Kimmins, (1993) reported minimum surface temperatures can be 5°C cooler in the clearcut. They also found that soil temperatures, in the clearcut, at 10 cm depth can reach daily maximums 5-10°C warmer and daily minimums that are 2°C cooler.

Daily fluctuations in the soil thermal regime were greater in the cut aspen treatment. There was greater insolation in the cutblock than the forest or edge sites.

Keeman and Kimmins (1993) reported that at night, a clearcut dissipated more energy by re-radiation, conduction, convection and evaporation than a forest site. The vegetation cover type can have a major effect on the soil thermal regime (Oke, 1989). Pierson and Wight (1991) found, in sagebrush pasture soils, the diurnal thermal amplitude was less beneath sagebrush than in the intervening spaces between sagebrushes. The thermal diurnal amplitude, at 1 cm depth, under sagebrush was similar to that at 10 cm depth in the open.

Greater soil temperature difference may not have occurred because of greater latent energy losses in the cutblock. Greater airflow and soil temperature would result in increased potential evapotranspiration rates. Miller's (1980) two dimensional energy budget model indicated that additional energy from the clearing would dissipate at the forest edge by increased evapotranspiration of the trees and convective air movement. Thus soil temperatures at the forest edge did not warm as significantly in the cutblock.

Dense aspen suckering and understorey plants on the cut treatments re-establish a partial vegetation cover. This could minimize the effects of the harvesting on soil temperatures in both the long and short term. Harvest practices should ensure successful regeneration of aspen. If too many residual trees are left in a harvest block, they could shade the ground and thus impede soil warming.

At the study sites, snow melt appeared more advanced in the open terrain than in the forest, but no detailed measurements were taken. Earlier spring snow melt and disturbance of the snowpack from harvesting can expose the ground to direct sunlight before the forest surface. Soils thus warmed sooner in the spring. Several studies found increased radiation in the clearcut advanced snowpack melt by 1-3 weeks in the clearcut compared to the forest (Meng et al, 1995, Keeman and Kimmins 1993, Kershaw, 1995).

3.5.6 Edge Effect

In this experiment, microclimate at the aspen forest edge was influenced by both the forest and cutblock environments. PAR values were intermediate between the forest and clearing treatments. Soil temperature was more influenced by the forest but wind speed was heavily influenced by wind direction. Malcom (1994) used a model to evaluate microclimate edge effects in forest fragments. At the forest edge, he determined that light and wind were determined by thickness of canopy and understorey foliage. Edge effect was determined by soil type, edge age, initial species composition, topography, wind exposure and disturbance type. Forest edges develop more lush understorey growth, because of less competition and more favourable environments (light, precipitation and temperature). This further altered the edge effects. At a forest edge, Chen et al (1993) and Chen et al

(1994) found that wind and solar radiation were intermediate between measurements in clearcut and interior forest, but temperature and moisture were not. Forest edge orientation crucially affected solar radiation, soil moisture, wind speed and relative humidity. If the forest edge in this study had been south-facing rather than a northwest orientated edge, the cutblock "influence" would have predominated because of the warmer, sunnier environment. Because the prevailing wind direction was from the northwest, the orientation of the forest edge would influence wind velocities. In this study, the edge was directly facing the prevailing winds with the maximum fetch across the cutblock. If the edge had been facing directly away from the prevailing winds, wind speeds at the forest edge would have been similar to the aspen forest.

In this study, there was no increase in air and soil temperatures or wind speed in the forests adjacent to cutblocks. Although these results indicate that cutblocks adjacent to aspen forests did not affect the forest microclimate, some research has shown the otherwise. Chen et al. (1995) found edge effects extended into the forest 20 to greater than 240 m and that daily maximum and minimum temperatures depended on the edge orientation. Most forest-cutblock edge effects depend on the size of the clearing and orientation on of the edge. Wind damage was greatest along west-facing forest edges of clearcuts (DeWalle, 1983) and directly related to clearcut fetch. Most windthrow occurred within two canopy tree heights from the forest edge. In this study, the microclimate of the cutblock did not penetrate to the microclimate station in the forest.

3.6 Conclusions

Forest, edge or cutblock microclimates were dominated by the stronger influence of the macroclimate. Harvesting increased PAR, soil temperature and airflow in the cutblock, but only increased PAR and sometimes wind speed at the forest edge. Orientation of the forest edge determined how much wind speed was affected by harvesting. Soil temperature at the edge was similar to the forest because of vegetation shading of the soil surface. The forest had the lowest PAR, soil temperature and wind values. For all treatments, daily mean air temperature did not change but daily extremes were significantly different for forest versus cut sites, but only when plants had foliage.

A flush of aspen suckers and re-growth of understorey plants in the clearings was sufficient to decrease the influence of cutting at the level of instrumentation for this study. Residual trees in the cutblocks also reduced the effects of harvesting. With the rapid re-establishment of the aspen canopy, the effect on microclimate should be short-lived. Since microclimate beneath an aspen canopy did not change significantly as the forest aged (Chapter 2), major impacts of harvesting the aspen forest will occur when the site becomes a cutblock. By assuring dense aspen regeneration and leaving residual trees in cutblocks, forest management can minimize the impact of logging on the forest microclimate.

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4.0 Conclusions

4.1 Microclimate of aspen forests

Because forestry activity will alter the age structure of the forest by eliminating the oldest aspen stands, microclimate of the boreal forest potentially could be altered and further impact native flora and fauna. Foresters want to minimize the disturbance to the environment and thus ensure forest use and productivity.

The first objective of this study was to compare microclimate of three age classes of aspen forest to determine if microclimate changes could be explained by shifts in structure and composition as the aspen forest aged. Climatic parameters of PAR, wind speed, air and soil temperature were compared from seven microclimate stations. Parameters were analyzed for their relationship to forest structure.

The internal microclimate of three age classes (young: 20-30, mature: 50-65 and old: 100+ years) of *Populus tremuloides* mixedwood of the southern boreal forest was weakly correlated to stand age. Hourly average measurements of photosynthetically active radiation (PAR), wind speed, air and soil temperature taken at the seven microclimate stations varied widely both within and between age classes. Lee et al (1995) reported a variability in forest structure and composition with age class. Therefore, it was intuitive that microclimate should also have wide variability with age class (Oke, 1989). Given the high degree of variation in the forest attributes and microclimatic variables that were measured, it was evident that greater than seven monitoring stations would be necessary to accurately characterize the microclimate of each age class stand and determine if there were age-induced microclimate relationships.

In this study, a greater correlation was found when microclimate was directly related to forest attributes. Aspen forest characteristics of understorey cover, type of organic matter and depth correlated better to the microclimate variables. Lee et al (1995) also found that aspen forest structure and composition changed as the stand aged. It could be tentatively concluded that microclimate will change as the forest structure and composition develops in association with aging. However, a decrease in one forest structure attribute (i.e. canopy cover) with forest age could result in an increase in insolation, but this predicted increase could be negated by changes in another forest characteristic (i.e. increasing shrub cover), with the result that soil temperatures did not increase as the forest aged. Such is the complexity of the interactions and processes operating with the aspen forest that were studied.

4.2 Logging effects on the microclimate of aspen forests

Logging will disturb the vegetation cover and create more forest edge. Keenan and Kimmins (1993) reported that cutting altered the microclimate and that these clearings potentially could influence the microclimate at the forest edge and within the forest. Forest regeneration or productivity could be reduced by changes in climate.

Microclimate of an aspen mixedwood (*Populus tremuloides*) forest, an aspen cutblock, and the edge of an aspen forest-cutblock were compared to evaluate the effects of logging. Replicates of each treatment were established in two stands. One additional microclimate station was installed to represent a forest without an adjacent logged stand. Cut sites had greater microclimate variability, because of greater structural variability (residual trees and slash) left after logging. Microclimate at the cutblock-forest edge was influenced by both the forest and the clearing environment. The block cut had higher values of PAR (photosynthetically active radiation), wind and soil temperature than the aspen forest. Wind direction determined edge wind speed due to fetch differences associated with orientation of the wind. Orientation of the cutblock-forest border relative to the prevailing wind direction would determine fetch, thus wind speed.

Mesoclimate and the solar cycle had a predominate effect on all parameters of the microclimate. As the aspen forest matured, microclimate changes were smaller when compared to microclimate changes caused by forest succession or different vegetation types (Ross et al, 1986). Aspen harvesting caused a major shift in vegetation cover. It also caused increases in PAR, temperature, wind and estimated potential evapotranspiration that were less than observed when coniferous forests were cut (Keenan and Kimmins, 1993). Unlike coniferous forest logging, rapid re-establishment of the aspen tree canopy after a disturbance reduced the severity and temporal effects of harvesting. Bladed areas, such as access roads and loading areas, will be more microclimatologically altered because of the greater environmental disturbance (Keenan and Kimmins, 1993).

The effects of logging aspen stands were less dramatic than harvesting coniferous stands, but it did change the microclimate of the clearing and the forest edge. Forestry cutting practices must minimize these changes by leaving residual clumps of trees and by minimizing disturbance to the organic mat. Dense aspen suckering effectively re-establishes an aspen forest microclimate in a short time interval following cutting.

4.3 Future Research Directions

This study was designed to examine may aspect of microclimate but did not include important variables such as topography, soil properties, humidity, and wind direction.

It is strongly recommended that future research examine the water balance of an aspen forest and cutblock. Changes in transpiration and evaporation rates should be significant. Energy used for latent heat could influence thermal conditions. Climate effects vegetation but so, too does vegetation influence climate at both the micro- and mesoscale.

Models need to be developed that use thermal and latent heat fluxes to better explain the climatological complexities of aspen forest canopies. Each structural change in the aging aspen forest could be studied individually. For example, assessing how changes in the canopy gaps affect the microclimate.

Spruce succession of an aspen canopy is common in the boreal forests of Alberta. Spruce replaces aspen because of more favourable environmental conditions such as microclimate. Detailed measurements of these microclimate changes need to be examined to assist in explaining such shifts in the ecosystem.

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